The treachery of strategic decisions.

An Actor-Network Theory perspective on the strategic decisions that produce new trains in the UK.

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy by Michael John King.

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Abstract

The production of new passenger trains can be characterised as a strategic decision, followed by a manufacturing stage. Typically, competing proposals are developed and refined, often over several years, until one emerges as the winner. The winning proposition will be manufactured and delivered into service some years later to carry passengers for 30 years or more.

However, there is a problem: evidence shows UK passenger trains getting heavier over time. Heavy trains increase fuel consumption and emissions, increase track damage and maintenance costs, and these impacts could last for the train's life and beyond. To address global challenges, like climate change, strategic decisions that produce outcomes like this need to be understood and improved.

To understand this phenomenon, I apply Actor-Network Theory (ANT) to Strategic Decision-Making. Using ANT, sometimes described as the sociology of translation, I theorise that different *propositions of trains* are *articulated* until one, typically, is selected as the winner to be *translated* and become a *realised train*. In this translation process I focus upon the development and articulation of propositions up to the point where a winner is selected. I propose that this occurs within a valuable '*place'* that I describe as a '*decision-laboratory*' – a site of active development where various actors can interact, experiment, model, measure, and speculate about the desired new trains.

My research finds that UK passenger trains have indeed got heavier over time, although this is not inevitable. Applying ANT to an historical analysis of the railways I show that the collection of resources that have acted as a train and the railways are more fluid than their iron and steel appearance might imply. A diverse material-semiotic configuration of entities can act as a train. Different configurations will have different attributes, including some that are heavier than others. Two recent strategic decisions – Thameslink and Crossrail – are investigated using ANT to understand how each decision-laboratory mobilised human and non-human actors to articulate propositions of the desired new trains. The realised trains, translated from the earlier winning propositions, are now in service and have been widely recognised for their lightweight designs.

To understand problematic outcomes, such as heavy trains, I propose three challenges common to all strategic decisions. The first (*treachery of models)* refers to the unbridgeable gap between experiments and reality – between propositions of trains and their translated realised forms. The second (*performativity of trains)* notes the socio-technical nature of trains, which means that, for example, people can compensate for inadequacies in the trains produced. The third (*society in the making*) reflects the difficulty of producing a train with a 30-year life while society can change around it.

I propose that improving strategic decision-making, and the outcomes that later emerge, can be achieved by improving the effectiveness of decision-laboratories. First, the decision-laboratory needs clear and prioritised objectives. Second, the decision-laboratory should be recognised as an active site of production, rather than a neutral, passive, and sterile place. Finally, the decision-laboratory should foster the exploratory side of its character and recognise the value of unplanned innovation.

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1 Introduction

1.1 The trials of producing new trains

On Monday 5th October 1829 a “trial of strength between terrifying monsters, hissing, spluttering, breathing fire and dropping red hot cinders” (Marshall, 1930, p. 1063) began at Rainhill near Liverpool. It was described as one of the strangest and momentous of all competitions, with crowds that came in wonder to see an “inanimate thing move itself on level ground” (ibid. p. 1063).

Three years earlier, an Act of Parliament had given approval to the opening of a “cheap and expeditious Communication between the two large trading Towns of *Liverpool* and *Manchester*” (His Majesty’s Government, 1826, p. 1385). Transport of goods and people between the Port of Liverpool and the factories of East Lancashire used canals and roads, which were viewed as expensive and of poor quality, respectively. Construction began on the railway in June 1826, and by 1829 was well advanced. However, the Directors of the new Liverpool and Manchester Railway (L&MR) Company faced a problem that they needed to resolve. They were unclear on the nature of the motive power that they should use for their railway. The Act gave authority for a *locomotive or moveable engine* to operate on the railway so long as it *consumed its own smoke*, with a threat of conviction if these new monsters emitted large volumes of smoke in a harmful or polluting manner.

By 1829, nearly every place where there was a mine had some sort of railway, with approximately 25 significant developments (Marshall, 1930, p. 1065) also supported by Acts of Parliament. Locomotion was provided in four different ways on these railways: horses; gravity; stationary engines with ropes; and locomotives. Horses could not deliver the desired speeds or scale of operation required for the L&MR. Gravity was not an option in this geography. This left the choice (**the strategic decision**) between stationary (fixed) and locomotive (moving) engines. The stationary engine was advanced and reliable compared to its locomotive cousin “wheezing, leaking at every pore, and often breaking down” (Marshall, 1930, p. 1065). The locomotive also had the disadvantage of running on rails that were not intended to carry the weight of the engine *and* its load. Locomotives were still in their infancy, with about 50 built in England, and only 26 doing useful work, including six on the Stockton and Darlington Railway (S&DR), the world's first public railway using locomotives.

To help with their decision, the Directors of the L&MR had arranged a visit to the S&DR in 1828. Following this, in early 1829, two leading engineers were commissioned to visit various collieries and report on the merits of locomotive and stationary engines. They were asked to consider the best "moving power" (Walker *et al.*, 1831) to be used on the new railway. The primary objective of the study was to determine comparative costs for the two alternatives – stationary and locomotive engines. The engineers used their studies and meetings **to model the L&MR** across the two alternatives for power.

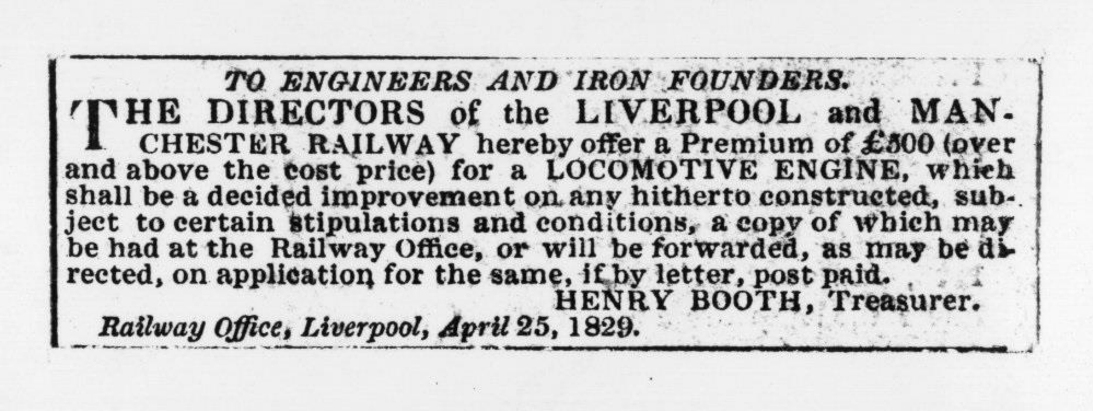
Their modelling calculated the cost of moving 4,000 tonnes over thirty miles (the approximate distance between Liverpool and Manchester) for 312 days of the year. This produced a "rate per ton per mile…0.2787 of a penny" (Walker *et al.*, 1831, p. 17) for the locomotive and a less expensive figure of 0.2134 of a penny per ton per mile for the stationary engine. However, the capital needed for the stationary engine was modelled as £100,862 1s 0d (c. £11Bn[1] in 2019 money), compared to a lower capital requirement of £90,963 14s 3d (c. £10Bn in 2019 money) for the locomotive. The engineers' report acknowledged that annual expense modelling had not included any estimate of wear on the railway, resulting from the additional weight of locomotives over stationary engines. This would depend upon the type of locomotive and its weight.

Both power options could *accommodate the public*, but the choice of stationary engines was viewed as intrinsically safer, because it did not involve high pressure engines operating near to people. However, the breakdown of a stationary engine potentially introduced a single point of failure that could disrupt an entire line, whereas a broken locomotive may only disrupt that single service, if it could be passed safely.

The engineers' report leaned towards fixed engines, but it was not clear cut. Stationary engines were more stable and could provide the ability to move large amounts of goods and people from the start of operations. By contrast, locomotives

[1] Bank of England Inflation Calculator: https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator

were less reliable, but could be introduced more gradually in proportion to the demand for transport. Choosing between the two remained a challenge for the L&MR Directors. They decided to test the potential of locomotive engines by offering a prize of £500 (Figure 1.1). This was to be awarded for a locomotive that improved on those currently operating, subject to certain *stipulations and conditions* created by the Directors and their advisors.


TO ENGINEERS AND IRON FOUNDERS.

THE DIRECTORS of the LIVERPOOL and MANCHESTER RAILWAY hereby offer a Premium of £500 (over and above the cost price) for a LOCOMOTIVE ENGINE, which shall be a decided improvement on any hitherto constructed, subject to certain stipulations and conditions, a copy of which may be had at the Railway Office, or will be forwarded, as may be directed, on application for the same, if by letter, post paid.

HENRY BOOTH, Treasurer.

Railway Office, Liverpool, April 25, 1829.

Figure 1.1 Advertisement for the Trials in the Liverpool Mercury, 1 May 1829.

Source: Railway Museum, https://www.railwaymuseum.org.uk/objects-and-stories/stephensons-rocket-rainhill-and-rise-locomotive

Eight stipulations and conditions were given (Walker *et al.*, 1831, p. 103) and these are summarised below, with some original usage, such as “Engine-man,” presented without updating to modern conventions:

1. The Engine must “consume its own smoke.”
2. If the Engine weighed six tons then it must be capable of drawing a train of carriages of 26 tons at 10 miles per hour, with steam pressure not exceeding 50 lbs per square inch.
3. There must be two safety valves, one of which must be completely out of the reach of the “Engine-man.”
4. The Engine and Boiler must rest on six wheels and the height, from the ground to the top of the chimney, “must not exceed fifteen feet.”
5. The weight of the “Machine” including water for the boiler must not exceed six tons and lighter was preferred.
6. A mercury gauge was required to show steam pressure.
7. The Engine must be delivered for trial at Liverpool before October 1, 1829.
8. The price of the winning Engine was not to exceed £550 when delivered.

Additionally, it was noted that the distance within rails was four feet eight and a half inches. A distance that would later become known as *standard gauge*, or Stephenson gauge after George Stephenson, who built the Stockton & Darlington Railway and its locomotives.

The first day of competition began on Tuesday, 6 October 1829. A starting post at Rainhill ran to a second post 1/8th of a mile away, where one of the judges stood. The next post, and another judge, were 1 ½ miles further, with the final post a further 1/8th mile ahead, where the engines would stop and return to the start. The public "were not idle spectators" (Walker *et al.*, 1831, p. 101) with a grandstand erected for several thousand people.

A weighbridge on site weighed the five competing locomotives and a weight to be hauled was calculated based on three times each locomotive's weight. As an example, the weight of *Rocket*, was 4 ¼ tons which gave a proportionate load of 12 ¾ tons. This load included *Rocket's* tender car carrying fuel and water, as well as two carriages loaded with stone to make the total 12 ¾ tons. For *Rocket* this represented a total "mass in motion" (Walker *et al.*, 1831, p. 105) of 17 tons.

Preparatory runs by the *Rocket* and *Novelty* locomotives were made on Tuesday 6 October 1829, but no record of fuel consumption or other factors were recorded. A dispute emerged regarding the method of assigning a load to *Novelty*. This stemmed from the different designs of *Novelty* and *Perseverance* compared to *Rocket* and *Sans Pareil*. The latter pair hauled a tender car behind to carry coal and water, whereas the former had no tender car, with coal and water carried on the locomotive. The different designs of *Rocket* and *Novelty* are shown in Figure 1.2 below.

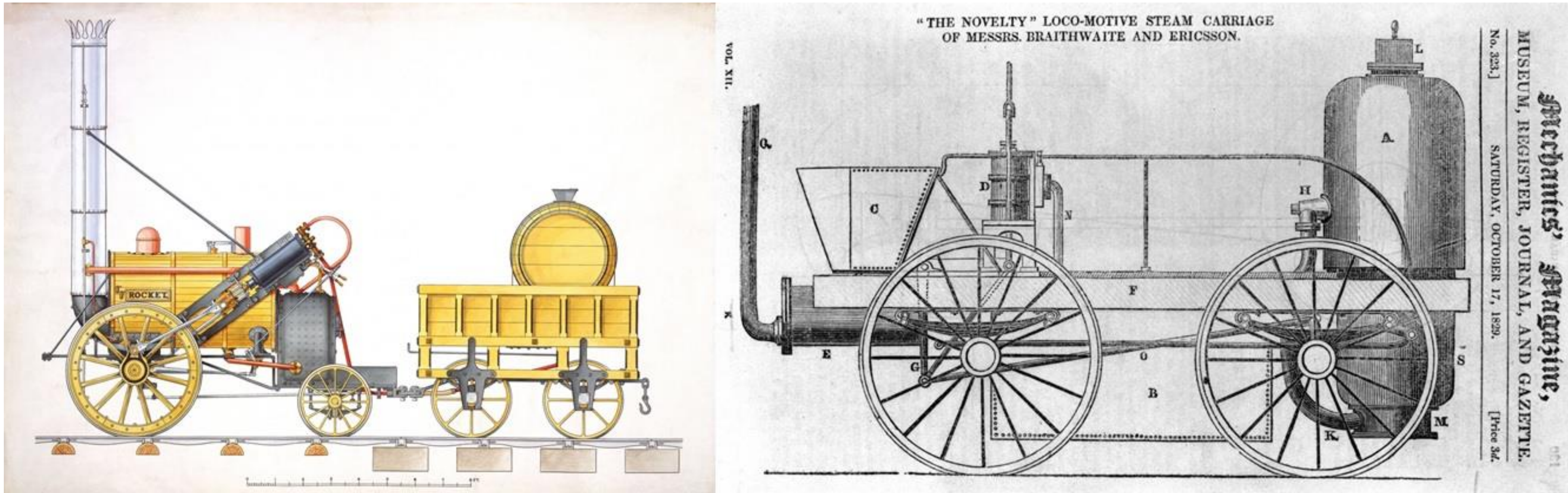
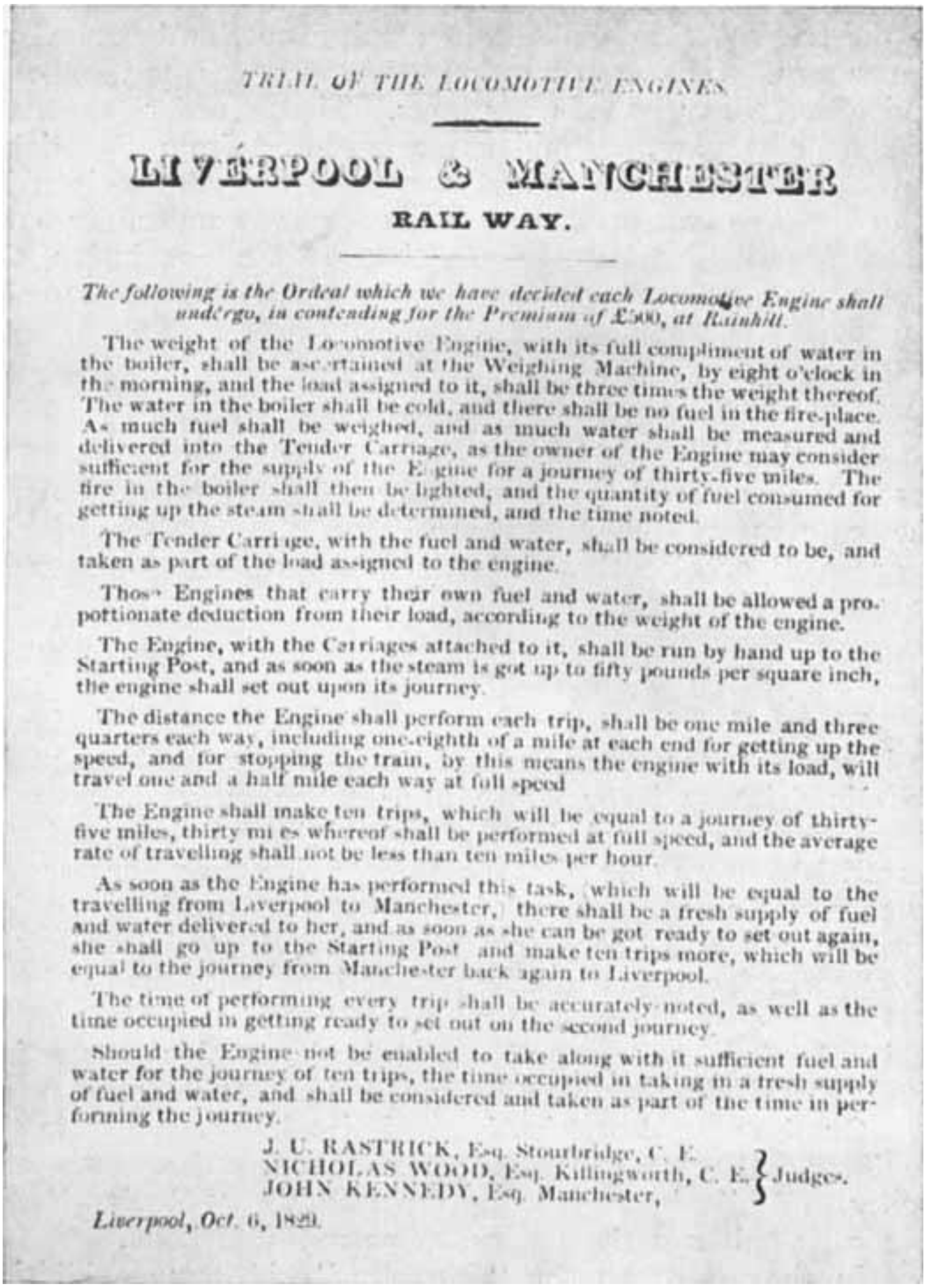


Figure 1.2 Rocket and Novelty locomotives

Rocket (left). Novelty (right)

Source: Railway Museum, https://www.railwaymuseum.org.uk/objects-and-stories/stephensons-rocket-rainhill-and-rise-locomotive

The calculation of proportionate load had included (and assumed) a tender car, but this needed adapting. On October 6th, the judges issued a new list of conditions in response to this dispute, with a copy shown below (Marshall, 1930, p. 1089).



TRIAL OF THE LOCOMOTIVE ENGINES.

LIVERPOOL & MANCHESTER

RAIL WAY.

The following is the Ordeal which we have decided each Locomotive Engine shall undergo, in contending for the Premium of £500, at Rainhill.

The weight of the Locomotive Engine, with its full compliment of water in the boiler, shall be ascertained at the Weighing Machine, by eight o'clock in the morning, and the load assigned to it, shall be three times the weight thereof. The water in the boiler shall be cold, and there shall be no fuel in the fire-place. As much fuel shall be weighed, and as much water shall be measured and delivered into the Tender Carriage, as the owner of the Engine may consider sufficient for the supply of the Engine for a journey of thirty-five miles. The fire in the boiler shall then be lighted, and the quantity of fuel consumed for getting up the steam shall be determined, and the time noted.

The Tender Carriage, with the fuel and water, shall be considered to be, and taken as part of the load assigned to the engine.

Those Engines that carry their own fuel and water, shall be allowed a proportionate deduction from their load, according to the weight of the engine.

The Engine, with the Carriages attached to it, shall be run by hand up to the Starting Post, and as soon as the steam is got up to fifty pounds per square inch, the engine shall set out upon its journey.

The distance the Engine shall perform each trip, shall be one mile and three quarters each way, including one-eighth of a mile at each end for getting up the speed, and for stopping the train, by this means the engine with its load, will travel one and a half mile each way at full speed

The Engine shall make ten trips, which will be equal to a journey of thirty-five miles, thirty miles whereof shall be performed at full speed, and the average rate of travelling shall not be less than ten miles per hour.

As soon as the Engine has performed this task, (which will be equal to the travelling from Liverpool to Manchester,) there shall be a fresh supply of fuel and water delivered to her, and as soon as she can be got ready to set out again, she shall go up to the Starting Post and make ten trips more, which will be equal to the journey from Manchester back again to Liverpool.

The time of performing every trip shall be accurately noted, as well as the time occupied in getting ready to set out on the second journey.

Should the Engine not be enabled to take along with it sufficient fuel and water for the journey of ten trips, the time occupied in taking in a fresh supply of fuel and water, and shall be considered and taken as part of the time in performing the journey.

J. U. RASTRICK, Esq. Stourbridge, C. E.
NICHOLAS WOOD, Esq. Killingworth, C. E. } Judges.
JOHN KENNEDY, Esq. Manchester,

Liverpool, Oct. 6, 1829.

Figure 1.3 Rainhill Trials. New Conditions issued 6 October 1829

It was confirmed that the tender car was to be considered as part of the proportionate load to be hauled, and engines that carry their own fuel and water were to be allowed a proportionate deduction from their allocated load.

The water and fuel in the locomotive were included in the total weight that was measured by the weighing machine. The amount of water and fuel was at the engine owner’s discretion but needed to be enough for a journey equal to 35 miles, the approximate distance between Liverpool and Manchester. The measuring posts were 1 ¾ mile from start to finish, including 1/8 mile at each end to accelerate and brake, with 1 ½ miles for full speed running. This meant that 10 trips each way totalled 35 miles, with 30 miles at full speed. The average speed could not be less than ten miles an hour for the Trialists to take part. The time of each trip was to be recorded, as was the time to prepare and depart for the next journey.

On Thursday 8th October 1829, Robert Stephenson’s *Rocket* twice completed the 10 trips and required distance. In the first of these “**experiments”** [emphasis added] (Walker *et al.*, 1831, p. 110) 30 miles were travelled in two hours 14 minutes 8 seconds, at an average speed of 13.4 mph. The second experiment saw the 30 miles completed in two hours six minutes 49 seconds at an average speed of 14.2 mph. The quantity of fuel consumed over these 70-mile tests was 1085 lbs. of coke, which, for a 17-ton total load, gave a figure of 0.91 lbs per ton per mile. The quantity of water used for the 70 miles was 580 imperial gallons.

On Saturday 10th October, *Novelty* was weighed at 3.1 tons. As *Novelty* carried its own water and coal on the locomotive, an alternative method was used to assign its load. After much discussion, a method was developed that defined the weight of *Novelty*, including its fuel and water, as 3.85 tons. The load allocated was to be 6.85 tons, in the form of two carriages loaded with stone, making the total mass in motion 10.7 tons, compared to the 17 tons of *Rocket’s* trial. *Novelty* began its first run, reaching an average speed above 15 mph, but on the return leg a pump burst and put an end to the trial. The pump was later repaired, and *Novelty* made several trips hauling a coach of people at 28 mph, but this was not part of the experiments. However, it was agreed that *Novelty* should be allowed another trial.

On Tuesday, the *Sans Pareil* was weighed at 4.75 tons. One of the conditions issued by the Directors was that if any Engine weighed more than 4.5 tons, then it must have six wheels (Marshall, 1930, p. 1067) and, since the Sans Pareil was not on six wheels, the Judges considered that it was not entitled to compete. The owner of the locomotive argued that the weighing machine was wrong, and, after discussion, it was agreed that the locomotive could run to see how it performed. The tender car with water and fuel weighed 3.3 tons and it was allocated three cars loaded with stones weighing 10.95 tons, making the total mass in motion 19.1 tons. On its eighth trip the Sans Pareil had a pump failure, but its 27 ½ miles at been achieved at a rate of 13 ¾ mph, with 274 imperial gallons of water consumed and 2.3 lbs. of coke per ton per mile for the whole mass moved.

October 11th was to be the day of the prize award. The *Novelty* began its second run, but a technical fault on the first return leg concluded its involvement and it was withdrawn. The owner of the *Sans Pareil* requested another trial but was refused by the judges because it was above weight and of a construction that they could not recommend. The *Perseverance* locomotive was unable to move at more than 5-6 mph, which may have been attributable to an accident on the way to the course. It was withdrawn. The *Cycloped* also was withdrawn without recording trial runs. The *Rocket* was agreed by all to be the winner. It had completed the *ordeal* and fulfilled every condition. Robert Stephenson made two additional trips without the additional loads at a speed of 35 mph.

The *Rocket* subsequently operated on the Liverpool and Manchester Railway until 1836, when it was sold and worked on the Brampton railway hauling coal from Midgeholme Colliery in Cumbria until 1844. Improved designs based upon *Rocket* formed the basis of L&MR operations, with Robert Stephenson's *Northumbrian* carrying the Prime Minister, the Duke of Wellington, at the opening ceremony on 15 September 1830. This day was marred by the tragic death of William Huskisson MP, struck by *Rocket* travelling in the opposite direction from Manchester to Liverpool.

Approximately 180 years later, and more than 200 miles from Rainhill, two railway competitions are underway with the same aim: to find the best new trains to run services on their railway. Like the Rainhill Trials, a competition with a significant prize is on offer to the winner, in the form of a large contract awarded for the provision of new trains. There are no hissing and spitting monsters on show for gathered crowds, but the *ordeal*, spanning many years, would provide a trial for all involved. This is not a choice between locomotives and stationary engines, but those ‘in charge’ (the Department for Transport, Transport for London) are keen to choose the best trains from a group of competitors. This is not a newly developed railway, but the new trains do need to work with changes and enhancements being made to the current railway infrastructure.

The history of the Thameslink and Crossrail trials is difficult to pin down, with some proposals dating back to the 1970s for Crossrail and 1980s for Thameslink. British Rail, the nationalised railway operator, investigated options in the 1980s and tried to persuade politicians and others to provide necessary funding. When British Rail was abolished by the privatisation process, the Strategic Rail Authority (SRA), a non-departmental public body, took on the role, until it too was abolished in 2004. Subsequently, the Department for Transport stepped forward to play a key role in the procurements for both Thameslink and Crossrail. With Crossrail the DfT was joined by Transport for London (TfL), the local government body responsible for transport in London. These two entities are very visibly involved, but there are others with an interest in the new trains and improvements to the railway.

This is not like the Liverpool & Manchester Railway, which had a Board consisting of merchants, bankers, engineers, and politicians. Instead, the parties interested in Crossrail and Thameslink are more dispersed. Local businesses are actively funding Crossrail through business rates and other mechanisms. Specialist engineering organisations act as advisers to the project sponsors, and form partnerships to respond to the call. Financing for the new trains involves public and private sources and institutions. Politicians whose constituencies align with the routes of the railways are brought into the strategic decision. The geography of where the trains are built, and not just where they operate, brings in representatives from further afield.

A network of actors develops further as the competition is announced through various channels, including publication (Figure 1.4 below) in the Official Journal of the European Union (OJEU) in 2008 for Thameslink and 2010 for Crossrail. The *contracting entity* is named as the DfT for Thameslink and TfL for Crossrail.

UK-London: rolling stock
2010/S 148-229137

PERIODIC INDICATIVE NOTICE - UTILITIES

Services

This notice is a call for competition No
This notice aims at reducing time-limits for receipt of tenders No
SECTION I: CONTRACTING ENTITY
I.1) **NAME, ADDRESSES AND CONTACT POINT(S)**
Transport for London
c/o Crossrail Ltd, CS28/G4/14, 25 Canada Square, Canary Wharf

Figure 1.4 Notice of the Crossrail Trains competition, published in the Official Journal of the European Union, November 2010

This OJEU notice describes the challenge and sets out early stipulations and conditions. Interested parties must answer a range of questions that will determine if they can be part of these developing networks and participate in subsequent stages of the competitions. Five companies pass this stage of the trials for Thameslink and four for Crossrail. The trials continue and the companies are provided with a more detailed set of requirements and conditions.

For Thameslink, a Train Technical Specification (TTS) has been created, containing more than 500 unique identifiers that describe various aspects of the desired future trains. For example, the TTS describes the length of the trains (maximum of 243m: TTS 5.1.3), the expected design life (not less than 35 years: TTS 9.1.1), and even the capacity of the windscreen wash system (3 days between top-ups: TTS 6.7.2). Thameslink participants are also given a Train Infrastructure Interface Specification (TIIS), with more than 250 unique identifiers describing interfaces between the train and the infrastructure on which it will operate. The TIIS was produced by Network Rail, the UK public sector organisation responsible for rail infrastructure. Network Rail also produced a Train Control Specification (TCS), containing more than 150 unique identifiers to describe aspects of the control systems that will signal and regulate the new trains on the busy network.

Crossrail also produced a Train Technical Specification (TTS) to "**embody** [emphasis added] those technical features considered necessary" (Schedule B1, p5). The Crossrail TTS contains more than 750 unique identifiers of the desired future trains. For example, TTS 3.2.1.4 requires a *maximum operating speed of 145kph on tangent level track in open air whilst travelling into a headwind of 50kph* and at all loading conditions. Like Thameslink, the Crossrail trains are to have a design life of

35 years (TTS 3.47.1.1). The gangways between carriages are to be wide enough *to allow at least two 95th percentile adult UK male passengers to pass each other* (TTS 3.26.1.2). The driver's cab must contain *two coat hooks* (TTS 3.40.3.1) among other features.

Like at Rainhill the experiments taking place require competitors to demonstrate the capabilities of their different proposals of trains. A scoring system is provided that describes how the proposed trains will be scored and ranked. There is no weighing machine, like at Rainhill, but there are plenty of measurement tools and techniques that are brought into the trials by Officials and provided to Participants. The experiments do not provide a grandstand for the audience, but they draw a lot of public attention at times. Both Thameslink and Crossrail competitions are delayed significantly, because of *external* events, including a General Election and a Global Financial Crisis. These events *act upon* the strategic decisions and contribute to updated rules that are reissued to competitors as the competition progresses. Some competitors withdraw during the process, but those that remain continue to demonstrate their *proposals of trains* in line with the revised stipulations and conditions.

Finally, the experiments conclude, and a winning train is selected. This train exists in "around 7,000 pages" (House of Commons Transport Committee, 2011, p. 63) and so it cannot give celebratory rides to passengers, like *Rocket* at the end of the Rainhill Trials. These more recent Trials have run for three years – from the Invitation To Tender (ITT) through to selection of a winner. The *ordeal* is over, for now, and the winners can celebrate.

Siemens were selected as preferred bidder for Thameslink in June 2011. The first Class 700 Thameslink trains entered service February 2016 and all trains were operational by June 2018. Bombardier were selected for Crossrail in February 2014. The first Class 345 Crossrail trains entered service June 2017, with the full service expected to be operational by 2021.

The description above borrows stylistically, but not theoretically, from Michel Foucault's book (1991), *Discipline and Punish*, in which Foucault juxtaposed the treatment of a convicted criminal in 1757, and the punishment of crimes in a jail some 80 years later. Foucault used this to raise questions about justice, discipline, punishment, and more. The events that I describe above are separated by 180 years, but the activities have a similar goal – to select new trains for railways. There are hissing and spitting monsters performing in front of a grandstand in 1829; and proposals of trains, contained within 7,000-page documents, performing in procurement competitions in the early 21st century. Both the historic and recent cases ultimately produce new trains that go on to deliver a railway service and carry passengers. *The Rocket* went on to operate successfully on the Liverpool and Manchester Railway for six years, followed by eight more years on a railway in Cumbria, England. The new trains for Thameslink and Crossrail first entered service in 2016, and 2017, respectively, and they are expected to have an operational life of more than 30 years.

The purpose of this introduction is to begin to describe the type of events that are going to be explored in the rest of this thesis. Events such as this are considered here as *strategic decisions* and the goal is to understand how we can make '*better'* strategic decisions. They are described as 'strategic decisions' to differentiate them from operational decisions, which typically occur more frequently and would be expected to be less important, or critical. The research will develop insight into *strategic decisions*, to help understand why they go wrong and how this can be improved.

When we talk about making *better* or *improved* strategic decisions then the word 'better' or 'improved' needs much more elaboration. In the case of the strategic decision at Rainhill, we know that *Rocket* went on to operate as part of the world's first inter-city passenger railway between Liverpool and Manchester. Improved designs based upon *Rocket* continued to operate on the L&MR for 15 years, before the railway merged to form a larger operation. After *Rocket's* success at the Rainhill Trials an enormous growth took place in the railways across Britain and the world, as part of the industrial revolution. *The Rocket* can now be viewed in a museum and has taken its place in history. By many measures *Rocket*, and the Ranhill Trials, can be described as an outstanding success. There is a strong case to be made that *Rocket* was indeed the *best* competitor at Rainhill, and the Trials did produce the *best* outcome.

It is too early to say how the new Thameslink and Crossrail trains will be judged, as they are still relatively new into service. A key driver for these new trains is to respond to capacity issues and to support the rapid movement of large amounts of people to and from London. The new trains will be judged by their ability to support this goal, but their success, or otherwise, will also be influenced by other factors, such as costs, passenger experience, and more. This research has a focus upon one attribute of the new trains: their weight. The reason for this focus will be discussed shortly, in section 1.3. However, for now it is sufficient to say that strategic decisions that produce excessively heavy trains can, in turn, produce excess emissions of greenhouse gases, and other pollutants for the 30+ year operational life of the trains and beyond.

This research will contribute to the practice of strategic decision-making and theory development. Actor-Network Theory (ANT), described in detail in Chapter 2, has provided a valuable perspective to understand agency and action in the strategic decisions that produce new trains. A contribution to literature is made by applying ANT to Strategic Decision-Making in new and novel ways.

Before developing the research further, it is important to locate myself, as the Researcher, within this work.

1.2 Personal statement – locating myself in this research

In the 1990s, while working for a global consulting business, I used to keep a scrapbook of newspaper and magazine clippings of things that I thought were interesting and could be relevant to my clients. The clippings included articles about the disposal of the Brent Spar oil rig in the North Sea by Shell (*The Financial Times*, 1995), the protests at the World Trade Organisation in Seattle in 1999, the challenges to Nike regarding practices in their extended supply chains (Hertz, 2001; Klein, 2001), and more. For my part I saw a common thread in these articles – that they reflected changing expectations of business in society. This was of interest to me, and I wanted to contribute in some way. Since then, I have followed the broad sustainability and corporate responsibility agenda ever since, and I am personally invested in the research contained in this thesis.

Through my consulting work and research in the late 1990s and early 2000s I saw increased use in business circles of phrases, such as *corporate social responsibility* and *sustainability*. Some corporations began to recognise, or at least talk about, a triple bottom line (Elkington, 1997) of economic, social and environmental responsibilities. I made my first contribution to research in this domain (King, 2001) by combining my interest in the emerging concept of sustainability with my consulting work, which often involved detailed financial analysis from an investor's perspective. The Dow Jones Sustainability Index (DJSI) had launched in 1999, using a methodology that assessed the social, environmental, and economic performance of large companies listed on the stock exchanges of the world. Companies with the highest scores using the DJSI method were ranked as '*sustainability leaders'* across various industrial sectors. My research (King, 2001) found that these sustainability leaders delivered superior returns for their shareholders compared to peers. It seemed that delivering against social, environmental, and economic objectives could be achieved, although it was undoubtedly complex.

There were increasing signs of activity and engagement in the business community. Sustainability reports were published, in line with emerging standards, and audited by independent external agents. Eco-efficiency schemes (Holliday, Schmidheiny and Watts, 2002) were good places for companies to start on their sustainability *journey*, as these initiatives could reduce waste and save money. Some CEOs talked about climbing *mount sustainability* (Anderson, 1999) and the radical transformation of old linear business models to 21st century cyclical models. There were many positive signs if you knew where to look. However, the gap between a growing discourse about sustainability and outcomes could still prove frustrating. Global challenges, such as climate change, were being discussed more by governments and corporations, but there was not the same level of action on the ground and in the numbers, with CO2 levels continuing to increase. For me this frustration reached a peak around 2006, when I saw a chart from the UK rail sector, where I had worked with clients since 2003.

1.3 A frustrating starting point: are UK trains getting heavier?

The motivation and focus for this research began with a chart (Figure 1.5 below) produced by Rail Research UK, a partnership between Britain's rail industry and UK universities. This chart showed UK trains getting heavier over time.

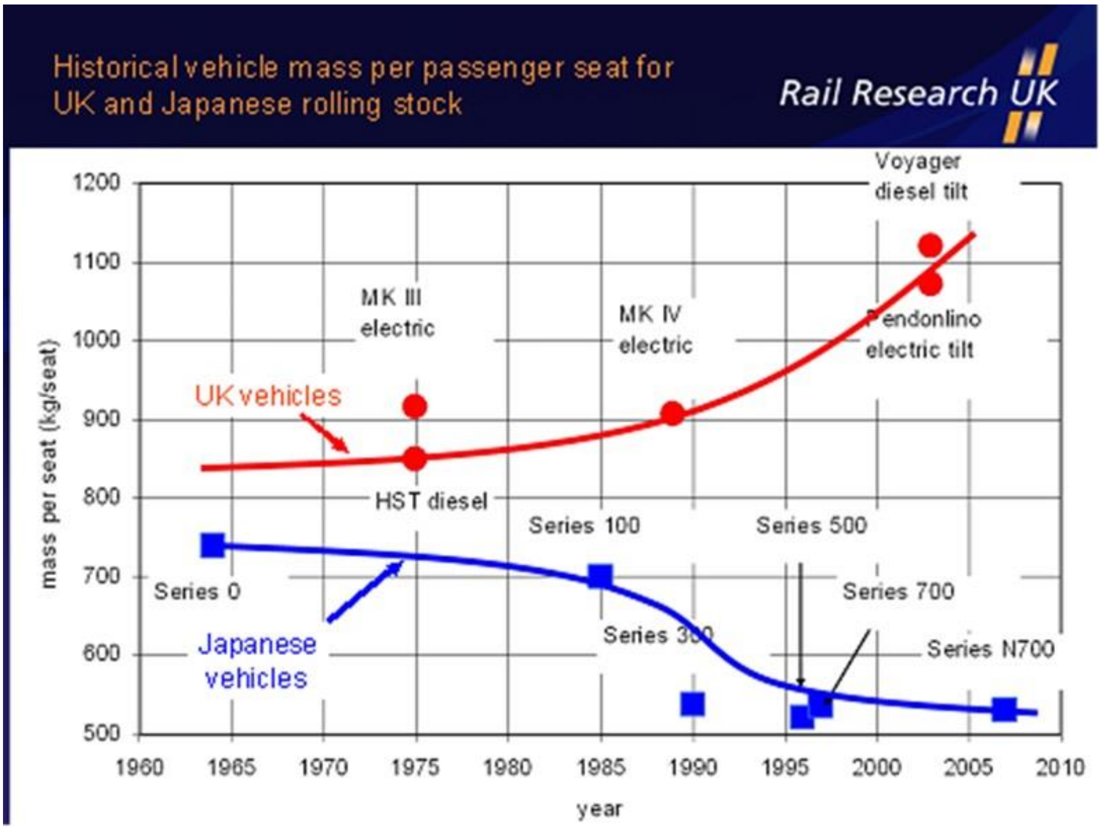


Figure 1.5 A chart from Rail Research UK showing trains getting heavier in the UK

Source: Rail Research UK presentation by Prof. Roderick A. Smith.

This chart was incredibly frustrating for someone keen to see progress on sustainability and action to address climate change. Heavier trains would be expected to increase fuel consumption and produce excess emissions of greenhouse gases and other pollutants. In terms of an environmental outcome, this would appear to be a failure, or at the very least, 'suboptimal'. From an economic perspective, heavier trains should increase damage to the track, impacting maintenance costs and the competitiveness of rail relative to other modes of travel. And these impacts might be with us for the 30-year operational life of the train and beyond.

This chart was the frustrating starting point for this research and so the remainder of this section will briefly explore the trains shown on this chart to help the reader understand and visualise these objects of interest. There are only 11 data points on this chart – five UK trains and six Japanese trains. Each will each be briefly described with reference back to its relevance to Figure 1.5 i.e., the year of introduction and the mass per seat of the train. Although these are all trains, the purpose of the following text is to **begin to make the case that there are many ways to configure trains, and different configurations will have different**

attributes. This thesis will show that a train is a more fluid concept than it might appear. Various configurations and collections of resources can act as a train. Some configurations will have attributes of increased weight compared to their peers. ANT is used to understand the strategic decisions that can produce such outcomes.

The five British trains shown in Figure 1.5 are a similar type of high-speed service, operating long-distance routes. For example, the Pendolino travels at a maximum speed of 125 mph and was introduced in 2002 on the West Coast of Britain operating between cities, such as London, Liverpool, and Glasgow. The Pendolino replaced the Mark III Electric train, also shown on the chart, which had operated the route since 1975. Although they are similar types of trains, there are also important differences within this group. For example, the Voyager diesel trains operate a long-distance service that is typically across the country, rather than between cities, for example running from Manchester to Totnes in Devon, in the south west of England. Diesel-powered trains, such as the Voyager, can travel potentially anywhere on the rail network, whereas electric-powered trains are constrained to the 38% of the network that is electrified in 2019 (Office of Rail and Road, 2019b, p. 1). The Voyager diesel trains have a shorter formation of five carriages, which provide 256 seats on a 118m long train compared to a 9-car Pendolino that is 216m long with 487 seats. The train operators must balance how they configure their trains, with the inefficiency of empty coaches on one side and overcrowding and lack of seats on the other.

Three of the five trains use electric power for traction and the other two use diesel power. Diesel-powered trains have onboard diesel motors and carry their own diesel fuel, which adds to weight. The electrically powered trains have onboard motors, and a device called a pantograph, which rises from the train roof to draw power from electrified overhead lines. On some parts of the UK network (for example, London Underground and Merseyrail) an electrified third rail is used to provide power to onboard electric motors. Three of the five are locomotive-hauled trains (Mark 3 electric, HST diesel, and Mark 4 Electric), which have power cars at each end pulling a rake of unpowered coaches. The power cars are significantly heavier than the coaches and carry no passengers. The Pendolino and Voyager trains are *Multiple Unit* formations (electric and diesel-powered respectively) with motors distributed across the different cars making up the train. Since there is no dedicated locomotive power car this means that every carriage also has some seats for passengers.

The configuration of additional services onboard will influence the availability of seating and the weight of the train. For example, kitchen facilities allow for onboard dining and can improve the passenger experience, which is especially important for longer distance services. First class seating reduces the number of seats compared to standard class seating configuration, as will the availability and type of toilet facilities and other onboard services.

The Pendolino and Voyager are both able to tilt as they travel at high speeds around curving parts of the UK network, which includes sections that were first built during the 19th century. Straight lines and flat gradients are not always possible when railway had to navigate hills and rivers, as well as powerful landlords, politicians, and other interested parties. Tilting technology allows a train to travel at high speeds on track with curves and bends, but the tilting train must ensure it avoids hitting bridges and other parts of the network and landscape. The railway *loading gauge* defines the maximum height and width for railway vehicles and their loads to ensure safe travel across the network. The UK’s loading gauge *acts upon* and shapes the trains shown in this chart to ensure their safe passage across the network.

This brief introduction has provided some insight into the diverse shape and form that trains can take. This is influenced by the type of service they provide, the geographies in which they operate, and various other forces and actions. The following diagrams show each of the five trains from Figure 1.5 with a visual representation of the length, weight, and number of seats for a typical train formation.

HST Train

The HST train is a locomotive-hauled train, consisting of two Class 43 diesel power cars at each end of a set of Mark 3 coaches. The diesel engines use an onboard supply of diesel fuel. The Power Cars carry no passengers and weigh significantly more than the coaches. The low seat count of 17, shown below for one coach, reflects a kitchen facility for onboard dining. First class carriages have 48 seats next to the dining car.

Weight (t)	**413.9**	70.3	33.5	33.6	33.6	33.6	33.6	38.2	33.7	33.7	70.3
Seats	**482**	0	65	76	76	76	76	17	48	48	0
Length	**219.6m**	17.8m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	17.8m

Figure 1.6 HST diesel with length, weight, and seat profile

Source: image of HST trainset with Class 43 diesel loco. (Marsden, 2014, p. 30)

Mark 3 electric train

The Mark 3 electric train is a locomotive-hauled train consisting of two Class 87 electric Power Cars at each end of a set of Mark 3 coaches. The electric engines draw power from the overhead AC lines. The Power Cars carry no passengers and weigh significantly more than the coaches. The low seat count of 18, for one coach shown below, reflects a kitchen facility for onboard dining.

Weight (t)	**480.8**	83.3	34.3	34.3	34.3	34.3	34.3	34.3	39.8	34.3	34.3	83.3
Seats	**564**	0	76	70	76	76	76	76	18	48	48	0
Length	**242.7m**	17.8m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	17.8m

Figure 1.7 Mk III Electric with length, weight, and seat profile

Source: image of Mk III Electric (Fox and Webster, 2001, p. 78)

Mark 4 electric train

The Mark 4 electric is a locomotive-hauled train consisting of a Class 91 electric power car at one end and a Driving Van Trailer (DVT) control car at the other, with a set of Mark 4 coaches. The power car has an electric engine that draws power from overhead AC lines and weighs significantly more than the coaches. The Power Car and DVT carry no passengers. The low seat count of 30 in one coach reflects kitchen facilities for onboard dining.

Weight (t)	**496.1**	84.0	39.5	40.8	40.8	40.8	39.4	43.2	41.3	40.7	42.1	43.5
Seats	**531**	0	76	76	76	76	68	30	41	42	46	0
Length	**249.4m**	19.4m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	23.0m	17.8m

Figure 1.8 Mk IV Electric with length, weight, and seat profile

Source: image of Mk IV Electric (Fox and Webster, 2001, p. 80)

Weight (t)	**282.6**	58.9	54.3	54.4	55.9	59.1
Seats	**256**	42	68	68	52	26
Length	**118.4m**	23.7m	23.7m	23.7m	23.7m	23.7m

Figure 1.9 Class 221 Voyager diesel tilt with length, weight, and seat profile

Source: image of Class 221 Voyager diesel title (Marsden, 2014, p. 149)

Voyager diesel tilting train

The Voyager diesel train is a Diesel Multiple Unit (DMU) with diesel motors distributed across the train and an onboard supply of diesel fuel. A five-car formation reflects the operation of the service across long-distances to more rural parts of the country. Driving motors at each end reduce the passenger seats available compared to intermediate motors in the middle cars. The low seat count of 26 in one coach is for first class seating in a driving motor car.

Pendolino electric tilting train

The Pendolino electric train is an Electric Multiple Unit (EMU) with electric motors distributed across the train. The train draws power from overhead AC lines. The train can tilt, which changes the profile of the train and allows it to travel at high speeds around bends. The low seat count of 18 in one coach reflects first class seating with kitchen facilities.

Weight (t)	**470.1**	56.3	52.3	51.2	52.3	45.5	52.3	53.2	52.5	54.5
Seats	**487**	18	39	55	76	76	76	48	64	46
Length	**216.9m**	24.8m	23.9m	23.9m	23.9m	23.9m	23.9m	23.9m	23.9m	24.8m

Figure 1.10 Pendolino class 390 electric tilt with length, weight, and seat profile

Source: Class 390 image (Marsden, 2014, p. 225)

In addition to the five British trains, Figure 1.5 also plotted the weight per seat of some Japanese trains for comparison over the same period. The Japanese trains were the Series 0, Series 100, Series 300, Series 500, Series 700, and Series N700. These trains operate on the Shinkansen line designed solely for high-speed services, with the latest N700 train capable of a maximum speed of 300 km/h. By contrast the UK trains have a maximum speed of 200 km/h and share the infrastructure with stopping passenger services and freight traffic. The Channel Tunnel Rail Link (High Speed 1) is currently the only dedicated high speed route in the UK, where trains can run at speeds up to 300 km/h.

This research is not performing an international study of train weight and there will be no exploration of the weight of UK trains compared to trains in various other countries. However, the Japanese trains are part of the original chart (Figure 1.5) which prompted this research and so it is appropriate to explore them briefly. The following pages provide photographs, brief commentary and analysis of their seat and weight attributes. Although this analysis will be limited in extent, it provides further support to the different ways in which trains can be configured and still act as trains – with different attributes resulting from these different configurations.

Shinkansen Series 0 and Series 100 trains

The Series 0 first entered service in 1964 as the first generation to operate the Shinkansen high speed line. It remained in service until 2008. The train could reach a maximum speed of 210 km/h (130 mph) initially, which increased to 220 km/h from 1986. They were originally introduced as 12-car sets but later lengthened to 16 cars. At 400 metres long the 16-car train had 1,340 seats and weighed 970 tonnes, which is 724 kg / seat.

The Series 100 entered service in 1985 and could reach a maximum speed of 220 km/h (137 mph). It remained in service until 2012. They operated in different formations and lengths, but the 16-car trainset was 402 metres long, had 1,321 seats and weighed 925 tonnes. This gives a figure of 700 kg / seat.

Figure 1.11 Shinkansen Series 0 and Series 100 rolling stock

Source of pictures: Series 0 By ナダテ (Nadate) - Own work, CC BY 3.0, Series 100 By © DAJF / Wikimedia Commons, CC BY-SA 3.0

Shinkansen Series 300 and Series 500 trains

The Series 300 entered service in 1992 and replaced the 100 series. It remained in service until 2012. The train could reach a maximum speed of 270 km/h (170 mph). It operated as 16-car sets and was 402 metres long, with 1,323 seats and weighed 710 tonnes. This gives a figure of 537 kg / seat.

The Series 500 entered service in 1997 and is still in service in the year 2020. The train could reach a maximum speed of 300 km/h (186 mph). The 16-car trainset was 404 metres long, had 1,324 seats and weighed 520 tonnes – a reduction of 17 tonnes on the Series 300. This gives a figure of 520 kg / seat.

Figure 1.12 Shinkansen Series 300 and Series 500 rolling stock

Source of pictures: Series 300 By Mitsuki-2368 - Own work, CC BY-SA 3.0, Series 500 By Mitsuki-2368 - Own work, CC BY-SA 3.0

Shinkansen Series 700 and Series N700 trains

The Series 700 first entered service in 1999. It is still in service in the year 2020. The train can reach a maximum speed of 285 km/h (177 mph). It operates as 8 or 16-car sets and the 16-car set is 405 metres long, with 1,323 seats and weighs 708 tonnes. This gives a figure of 535 kg / seat.

The Series N700 entered service in 2007 and could reach a maximum speed of 300 km/h (186 mph). It is still in service in the year 2020. The 16-car trainset was 405 metres long, has 1,323 seats and weighs 715 tonnes. This gives a figure of 540 kg / seat.

Figure 1.13 Shinkansen Series 700 and Series N700 rolling stock

Source of pictures: Series 700 By Scfema - Own work, CC BY-SA 3.0, Series N700 by Mitsuki-2368 - Own work, CC BY-SA 3.0

Unlike the mix of power sources for the UK trains, all Shinkansen trains shown here are Electric Multiple Units (EMUs), with electrically powered motors distributed across most of the cars. Shinkansen trains with 16 cars can obviously carry more people than, for example, a Pendolino with nine cars, and so simple comparisons using metrics, such as kg per seat need to be treated with caution. Chapter 4 will explore Figure 1.5 and the weight of UK trains in more detail, however, for the purpose of this introduction it is worth noting that if we normalise train weight relative to train length then this shows the same results as Figure 1.5. The chart below (Figure 1.14) shows Japanese trains (blue line with square markers) getting lighter over time, whereas the UK trains (red line with circle markers) have got heavier per metre of train length.

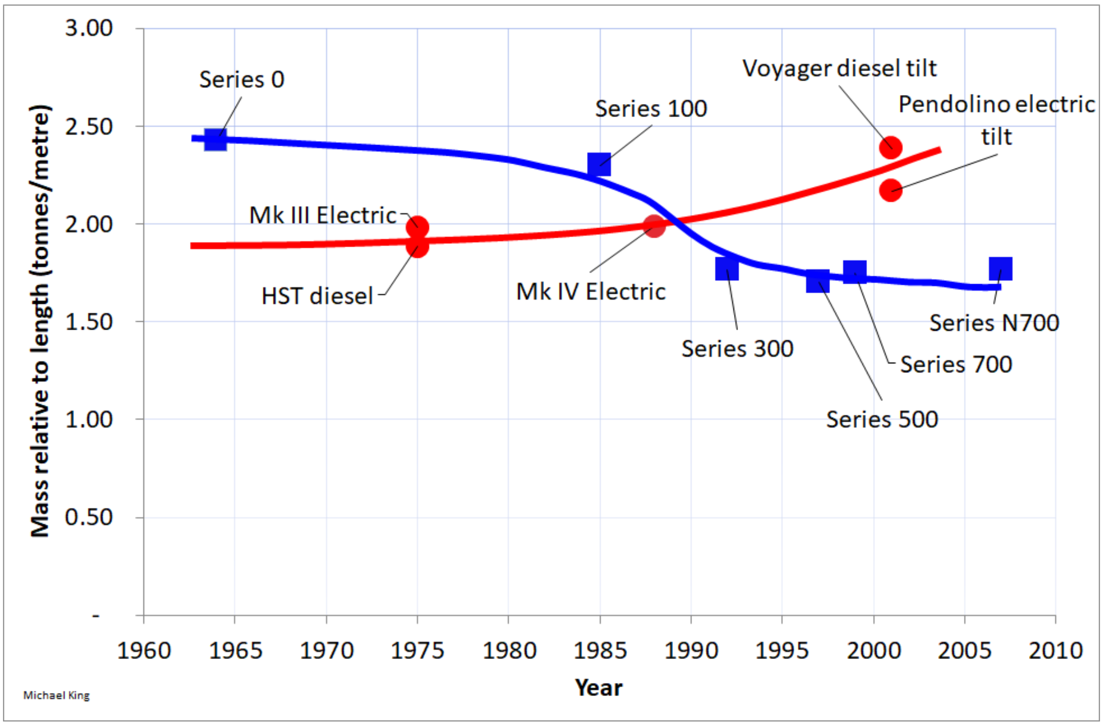


Figure 1.14 Weight relative to train length for tbe UK and Japanese trains

The reduction in weight per seat (Figure 1.5) and weight per metre of train length (Figure 1.14) supports a view that the "history of the Shinkansen is the history of light-weighting" (Wright, 2009) and this has been achieved as maximum speed and power have also increased.

If we ignore weight briefly and look only at the provision of seats per metre of train length, then we see the results in Table 1.1 below.

Table 1.1 Comparison of the number of seats and train length for certain UK and Japanese Trains

Train	Seats	Train length	Seats / m
HST diesel	482	220m	2.19
Mk III Electric	564	243m	2.32
Mk IV Electric	531	249m	2.13
Pendolino	487	217m	2.25
Voyager - diesel tilt	256	118m	2.16
Series 0	1340	400m	3.35
Series 100	1321	402m	3.29
Series 300	1323	402m	3.29
Series 500	1324	404m	3.28
Series 700	1323	405m	3.27
Series N700	1323	405m	3.27

The Shinkansen trains have more seats per metre, even though the UK and Japanese trains run on the same *standard gauge* track, with a width of 1435 mm between the inside rails of the track. Track gauge may be the same, however, the Shinkansen carriages are 3.3m wide, whereas UK trains, like the Pendolino, are 2.7m wide. Differences such as this reflect the fact that the Shinkansen trains run on a dedicated high-speed line, whereas the UK trains are *acted upon* by UK *loading gauge* and infrastructure, with a history dating back to the 19th century, and they are required to share this infrastructure with stopping services and freight traffic.

This research is not going to complete an in-depth international comparison and the Japanese trains will not be investigated further in any detail. However, the Japanese trains do play a role in the following analysis, and the story that will be developed in this thesis. They provide evidence that **the inevitability of weight increase should be treated sceptically.** The Japanese trains have reduced their weight per seat

(Figure 1.5), even though new trains are likely to have added modern features, such as air conditioning, electric doors, improved accessibility, and so on. Like for like comparisons should be treated warily, but so should any feeling of inevitability regarding train weight.

During the complex and lengthy action that produced the trains shown in Figure 1.5, it is highly unlikely that anyone said: *'Make sure they are heavy.'* But this has happened. **This research wants to understand how this could have happened, and how this could be improved in the future. Actor-Network Theory will be used to provide a richer understanding of how strategic decisions can produce such outcomes.**

1.4 A summary of the thesis

This thesis uses ANT to argue, firstly, that there are many ways to configure trains and **an outcome of heavy trains is one of many possibilities**. Secondly, **strategic decision-making should be understood as a collective action**, involving a diverse collection of actors. For example, Alstom manufactured the Pendolino train, but the tunnels and curving tracks of UK rail infrastructure also act upon its final shape and attributes. The third element of this thesis argues that **during a strategic decision, a valuable 'place' is often created that is described metaphorically as a *decision-laboratory***. This place centred around the Rainhill Trials for the strategic decision that selected *Rocket*. For the Thameslink and Crossrail strategic decisions this place is more nebulous but is dispersed around the procurement processes. These decision-laboratories bring actors together in an active and collective process to develop *propositions* – propositions of new trains in this case. The fourth element of this thesis affirms that **the winning proposition is the most articulate within the modelled environment of the decision-laboratory**. The wining proposal of a train is not the best train, it is the best proposition within the decision-laboratory. The effectiveness of the laboratory will be discovered later, when the proposition is translated into its realised form. In the case of *Rocket* the Rainhill experiments using a modelled Liverpool & Manchester Railway produced a successful outcome. The new Thameslink and Crossrail trains are still early in their service and it remains to be seen whether those decision-laboratories were effective or not. The final element of the thesis argues that, **given the importance of these places, described as**

decision-laboratories, then they should be a focus for improving strategic decision-making.

The concluding thesis is: if we can improve decision-laboratories, then we can improve strategic decisions and associated outcomes.

1.5 Thesis organisation

Two theory-building chapters follow this introduction.

The first part of theory-building (Chapter 2) **reviews the literature** to develop a theoretical approach to understand the phenomenon of heavy trains. Three bodies of literature were accessed to understand different aspects related to this research. The Decision-Making literature was used to understand decisions and, specifically, strategic decisions. The Social Issues in Management literature was used to understand how organisations respond to and act upon environmental issues, such as climate change and greenhouse gas emissions. Actor-Network Theory was the final body of literature accessed and became the primary theoretical lens to understand how trains act and different configurations of a train will have different attributes.

Chapter 3 is the second part of theory-building and it explains the *story of this research,* how it developed over time, and the **approaches employed** to arrive at the final approach. This chapter describes research approaches that were explored but could not be pursued for reasons that are explained. The final approach learnt from and built upon these lessons.

Chapter 4 focuses upon the **outcome of heavy trains**. Figure 1.5 was the frustrating starting point for this research, but the source data for this chart was not available. Also, there were only five British trains represented on the chart, which is an extremely limited dataset on which to base research. Therefore, Chapter 4 develops a detailed analysis of the weight per seat of UK rolling stock. This provides a platform for the following two chapters, which **use ANT to understand the strategic decisions that produce new trains**.

Chapter 5 builds an **historical analysis** of the railways in Britain and applies Actor-Network Theory to understand how the railways and new trains have been produced and configured over time. **The primary purpose of this chapter is to demonstrate that trains and railways are fluid configurations of resources** that have changed over time and will continue to change. This chapter covers a period that starts before the Ranhill Trials of 1829 through to recent trains operating on the current railway in 2020.

Chapter 6 focuses upon **two recent strategic decisions to produce new trains** – Thameslink and Crossrail. **Actor-Network Theory is used to understand the strategic decisions that produced these new trains**. The trains for Thameslink and Crossrail are operational on the UK railway and so the outcome of the strategic decisions can be assessed, specifically in terms of the weight attribute of the new trains.

Chapter 7 reflects upon the application of ANT to Strategic Decision-Making and the value that can be gained to understand this complex social process using this theoretical approach. **This theoretical approach, and the analysis in Chapters 4, 5, and 6, are then used to understand how strategic decision-making can produce heavy trains as shown in Figure 1.5 that prompted this research.** Challenges for all strategic decision-making – not just the production of new trains – are developed, with ideas for improving this critically important social activity.

2 Literature Review and Theory Development

To help understand the phenomenon of heavy trains, and how this outcome could have happened, three bodies of literature were accessed. They each brought different perspectives to understand the research problem.

The first literature, broadly defined as **Social Issues in Management (SIM)**, draws mostly from management and business studies. This literature was accessed to understand how the organisations involved in this action manage environmental and social responsibilities. Modern trains are manufactured by global corporations, such as Bombardier, Siemens, and others. Public organisations may not have a profit imperative but there are still requirements to justify use of funds and avoid unnecessary costs.

The second body of literature focused specifically upon **decision-making.** This draws from management studies and the cognitive and behavioural sciences and has a focus upon decision-making within organisations. This body of work helped to develop insights about decisions and specifically strategic decisions, such as the production of new trains.

The third body of literature is **Actor-Network Theory** (ANT). This literature was initially introduced because it evolved from Science and Technology Studies (STS), and trains are a form of technology. As the literature review progressed, my focus moved towards Actor-Network Theory as the main theoretical lens because it provided a valuable perspective to understand action, as explained later in this chapter. A theoretical model, which draws heavily from the ANT literature, was created for the research, and is described in section 2.4.

Each of these three literatures has contributed towards this thesis. **However, the main contribution to literature and theory that is made here is through the novel application of ANT to Strategic Decision-Making**. As will be explored shortly in this Chapter’s review of the strategic decision-making literature, strategic decisions are ambiguous in terms of who and what is involved, when they begin and end, and how their outcomes are assessed. The weight of trains produced by strategic decisions are central to this research because excessively heavy trains are expected to produce excess greenhouse gas emissions, as will be discussed in more detail in

Chapter 4. Strategic decisions to procure new trains are analysed by applying ANT and its network-based view of action as a ‘toolkit’ to understand how an outcome of heavy trains could have been produced.

The format of the following sections is to first present an overview of key developments and themes within each literature, before then reviewing how this helps to understand strategic decisions and the production of heavy trains.

2.1 Social Issues in Management (SIM)

This literature is based upon a premise that “business and society are intricately connected” (Wood, 1991b, p. 384). It was accessed because organisations are involved in the strategic decisions to produce new trains, and this research is interested in how organisations respond to social issues, such as climate change. This literature became a secondary focus as ANT emerged as the main theoretical lens to understand strategic decision-making. What follows is an overview of the key themes in the literature and its development over time, before summarising its relevance to this research.

2.1.1 Key themes and development over time

The SIM literature revolves around different conceptions of the purpose of the firm and a longstanding debate regarding the role of business in society. This is reflected in various concepts such as Corporate Social Responsibility (CSR) (Drucker, 1984; Frederick, 1994; Moir, 2001; Muller, 2006; Freeman and Moutchnik, 2013), Sustainability (Anderson, 1999; Berns *et al.*, 2009), and the triple bottom line (Elkington, 1997; McDonough and Braungart, 2002).

The modern SIM literature is often said to start with the work of Adolf Berle and Gardiner Means (1932), a lawyer and an economist. Written during the Great Depression, this important work analysed the corporation – the “dominant institution of the modern world” (Berle and Means, 1932, p. 313). At this time, owners (principals) were becoming increasingly distant and removed from managers (agents) running organisations. This principal-agent problem, with a history dating back to Adam Smith, essentially asks whose interests should be primarily served by a firm and its managers. Berle and Means argued that this separation meant that firms were increasingly being run for the benefit of managers, at the expense of shareholders *and other parties* that had an interest in these large organisations. To address this, they proposed that an independent body – a "purely neutral technocracy" (Berle and Means, 1932, p. 312) – could weigh up competing interests and demands and determine appropriate organisational action. This solution did not gain any traction, but the idea that business had "social responsibilities that transcend obligations to owners of stockholders" (Bowen, 1953, p. 4) did take root.

The most famous advocate against this idea was Milton Friedman, who believed this would "undermine the very foundation of our free society" (Friedman, 1962, p. 133) and harm the vital economic role of business within society. From this perspective, the "social responsibility of business is to increase its profits…[while following] basic rules of the society, both those embodied in law and those embodied in ethical custom" (Friedman, 1970, p. 121). Business was seen purely as an economic and wealth maximising entity, with managers who do not have the skills or remit to allocate company funds to social issues.

In line with Friedman's thinking, a *theory of the firm* gained increasing acceptance, which saw the corporation as a "nexus for contracting relationships among individuals" (Jensen and Meckling, 1976, p. 310). Within the organisation a multitude of complex relationships come together, and conflicting objectives are resolved. Employees give their labour in return for pay, suppliers provide goods and services, and so on. This theory recognised that an agent's (manager's) interests can diverge from an owner's, and when this happens it can be managed through efforts to re-align those incentives, or by implementing controls and procedures to monitor managerial behaviour. Board oversight and share options schemes are modern day responses to align executive incentives with the economic objectives of investors. This theory of the firm, as a *nexus of contracts*, recognises claims upon the firm from employees and communities, but this is seen as a *contractual* relationship. The value of this construct is questionable, however, when many business relationships with "'communities' can be so vague" (Donaldson and Preston, 1995, p. 85) that they cannot really be described as a *contract*.

Claims upon the firm that are more general and dispersed also highlight the limitations of this contractual theory. For example, problems of the *commons* (Hardin, 1968), such as climate change, pollution and congestion, do not present obvious economic opportunity for business. An economic view of the firm would argue this is not the responsibility of organisations, rather public policy intervention is needed, such as legal regulation, liability, ethical codes, and more. Taxes, such as a carbon tax, are often preferred by economists, so that the price signal can still be used to drive incentives and behaviour. However, an example can illustrate the limitations of this line of thinking in practice. At a high-profile speech at Stanford University in 1997, the CEO of BP, John Browne, stated that climate change should be "taken seriously by the society **of which we are part** [emphasis added]" (Browne, 1997). This apparent recognition of the importance of climate change, and BP's responsibilities, was a landmark moment, in many ways akin to the tobacco companies recognising their responsibility for the impact of their products. However, BP's financial accounts for 2017 – some 20 years after John Browne's speech – show that Crude Oil, Oil Products and natural gas accounted for at least 94% of the company's sales (BP, 2017, p. 142). This could be viewed as a sign of *greenwash,* but in the same 2017 annual report, BP called for carbon pricing to be implemented by governments, because this "provides the right incentives for everyone" (BP, 2017, p. 50) to reduce emissions. This call for carbon pricing aligns with an economic view of the firm that recognises the limited ability of organisations to respond to such complex social issues. Responsibility for such societal outcomes is placed in the hands of politicians and regulators, who must define the rules and context in which organisations operate. Issues like climate change may indeed require governments to act, but organisations, and the people within them, would recognise the risks of inaction if they ignore their **responsibility** with respect to societal issues like climate change.

The concept of responsibility has played a key role within the SIM literature. It is argued that society grants legitimacy (Davis, 1973) to corporations – often described as a *license to operate* – and this license can be removed, if an implicit trust is breached. Moral and ethical issues can suddenly expose corporate practices, which may be legally correct, but do not stand scrutiny under public gaze. This **societal-level responsibility** is applicable to all organisations. Below this societal responsibility a principle of **public responsibility** (Preston and Post, 1981) means that organisations are responsible for "outcomes related to their primary and secondary areas of involvement with society" (Wood, 1991a, p. 697). Below this organisational responsibility there is a **principle of managerial discretion** (Wood, 1991b, p. 696), which states that individuals cannot avoid their responsibility by reference to organisational rules and procedures. Managers are not removed from societal norms and responsibilities when they work within an organisation.

The SIM literature is managerial in nature, and recognises that it is often managers that are required to resolve genuine organisational dilemmas (Margolis and Walsh, 2003, p. 280), when competing expectations and responsibilities of the organisation do not align. Managers are aware of the economic needs of the organisation, but they are not simply profit maximising agents, rather they try to balance competing needs and interests. When faced with complex situations, managers do not seek optimal economic outcomes, rather they achieve results that are somehow *good enough*. The organisation may help and guide managers in this balancing process, by providing “principles and guidelines for managing trade-offs” (Margolis and Walsh, 2003, pp. 282–284), such as codes of conduct. Although this organisational support can help to guide behaviour and decision-making, it remains open to managerial interpretation.

In response to the complex reality of modern organisations a *stakeholder theory of the firm* came to prominence, which sought to “broaden management's vision of its roles and responsibilities beyond the profit maximization function” (Mitchell, Agle and Wood, 1997, p. 855). Stakeholder theory claimed that, in practice, there are many groups that play a vital role in the success of the business enterprise. In his important work, Freeman defined (1984, p. 25) a stakeholder as “any group or individual who can affect or is affected by the achievement of the firm’s objectives.” This theory is managerial in nature, because it recognises the centrality of managers as “the only group of stakeholders with direct control over the decision-making apparatus of the firm” (Hill and Jones, 1992, p. 134). However, managers are *in a relationship* with stakeholders, and **it is this stakeholder-manager relationship that explains action**. This begins to blur our understanding of action and moves it beyond organisational boundaries. Business and other groups within society are “interwoven rather than distinct entities” (Wood, 1991a, p. 695), with action resulting from interactions across this network. Not all stakeholders in this network are equal in their ability to influence companies to act in *socially responsible ways* (Campbell, 2007).

2.1.2 Relevance to this research

I think it is clear from the SIM literature that organisations involved in the production of trains are **responsible** for the associated impacts of products they have manufactured, helped to produce, or bring about. Heavy trains, that consume excess energy and emit greenhouse gases and other pollutants, are the responsibility of the organisations involved in producing them. This responsibility exists at different levels of analysis. At the societal level, these organisations have a responsibility because they are part of society, and climate change is a societal issue. At the organisational level, they have direct responsibility for the impact of the products and services they produce. At the individual level, managerial discretion means that individual managers cannot avoid personal responsibility by reference to organisational policies and procedures.

However, despite these responsibilities, heavy trains still happened. This could suggest that these theoretical responsibilities do not really exist, or they are so weakly applied in practice, that organisations can effectively ignore them. An alternative explanation is that trains produce many outcomes for society. Excess weight and emissions are a negative outcome, but the same trains move a lot of people at speed around the county and may produce relatively less emissions than alternative modes of transport. Additionally, trains provide employment, connect people with employment opportunities, and deliver many other positive and negative outcomes.

An economic view of the firm, recognising the limits of organisations, might argue that if we want lightweight trains, then we need to provide the right economic incentives, such as carbon taxes, so that it is in organisations' economic interest to achieve this. If there is an economic incentive to reduce weight, then managers would be expected to allocate resource and effort towards this outcome. This line of reasoning would bring legislators and rule setters into sight as an important *cause* of heavy trains, through their inaction. In the case of procurement competitions this would be the organisations running the competition, such as DfT.

In response to this economic view of the firm, the SIM literature does not advocate simplistically that organisations should achieve social goals, such as reducing unnecessary emissions, when it means engaging in loss-making activities. However, this literature does argue that organisations and their managers have real responsibilities, which cannot be dismissed by reference to the financial accounts or the inaction of legislators. The managerial nature of the SIM literature recognises an active role for managers to develop a response that resolves trade-offs across complex demands and external pressures. The organisational boundary does not mean that organisations are “unitary actors” (Pache and Santos, 2010, p. 456) when they are faced with complex demands and expectations. Stakeholder theory introduces an **expanded view of action that goes beyond organisational boundaries**. Stakeholder theory still recognises the critical role of managers, but the ability of stakeholders to influence organisations is explicitly recognised. Stakeholders’ ability to influence is related to the *power, legitimacy and urgency* (Mitchell, Agle and Wood, 1997) that exists across the network of relationships with the organisation and other stakeholders.

Issues such as climate change do not have a specific stakeholder but are, in theory, society’s problem, which can make them diffuse and vague. The government can *represent* society and the climate through public policy interventions, regulatory structures, carbon taxes or similar measures. NGOs and similar organisations may also give climate change a voice and greater representation, but these organisations are rarely involved directly in the production of trains. A stakeholder view of heavy trains could posit that stakeholders with an interest in the energy use and emissions of trains had less power, legitimacy, and urgency than other competing demands. This will be considered within the analysis in Chapter 6 to understand how energy and the climate is *represented* in the strategic decisions to produce new trains.

To conclude, central to the SIM literature is a debate about the purpose of corporations within society: who they should serve, and what outcomes they should produce. On one side, it is the responsibility of public policy to set the rules, and the responsibility of private firms to focus upon maximising profits. On the other side of this argument is a recognition that, in practice, this situation is more complicated. It is often managers within organisations who must determine how they respond to various “social ills” (Margolis and Walsh, 2003) within society, of which their organisations are a part. The production of trains involves private and public organisations, with competing demands placed upon all to balance cost, quality, reliability, and many other factors. Stakeholder theory introduces a **relational view**

of action that moves beyond organisational boundaries and recognises the interconnectedness of external stakeholders, organisations, and managers. This will be developed further in the Actor-Network Theory review later in this chapter.

2.2 Strategic Decision-Making (SDM)

This literature was accessed because the action to produce new trains is described in this research as a *strategic decision*, to differentiate it from operational and everyday decisions. The following provides an overview of the key themes in the literature and its development over time, before summarising its relevance to this research.

2.2.1 Key themes and development over time

Defining what a decision is, when it is made, and who makes it have all, at times, "turned out to be problematic" (March, Simon and Guetzkow, 1993, p. 3). However, a distinction can be made between the *decision process*, and some critical point when a *decision is made*. Within an organisation a decision is a "specific commitment to action" (Mintzberg, Raisinghani and Theoret, 1976, p. 246) and usually involves a commitment of organisational resources. Compared to operational or more everyday decision-making the literature recognises that strategic decisions are "important, in terms of the actions taken, the resources committed, or the precedents set" (Mintzberg, Raisinghani and Theoret, 1976, p. 246).

The decision-making literature recognises an *expected* way of making decisions that has varied across history and societies. In other historical and cultural contexts it has been expected and acceptable that "decision-makers consulted oracles and prayed for revelations" (March, Simon and Guetzkow, 1993, p. 17). Central to modern decision-making is a focus upon rationality – with managers making decisions supported by information and decision-making tools. Each of these elements will be explored next.

Information is central to modern decision-making but it is prone to bias and can be a "device for manipulating the decision" (Cyert and March, 1992, p. 79). Therefore, information should be more accurately considered and described as *contested* information (Hans de Bruijn and Martijn Leijten, 2008, p. 85), rather than *objective* information.

Tools and instruments are not neutral in decision-making. They can be used by project promoters (Vickerman, 2008, p. 66) to reinforce supposed wider benefits in support of the promoters' desired outcomes. Different results can be achieved by changing assumptions, analytical approaches, and techniques. For example, the choice of discount rates can cause economic costs and benefits in the long term to be discounted towards zero. The boundaries of the system of interest can be narrowed, widened, or moved to prefer one outcome over another.

Overall, decision-making should be viewed as rational, but only *boundedly so* (March, Simon and Guetzkow, 1993). Organisations are not "omnisciently rational" (Cyert and March, 1992, p. 117) when they make decisions, rather they respond to complex environments and problems by making, in effect, **good guesses**. Instead of a comprehensive and exhaustive evaluation of costs and benefits, a *satisficing* approach to options and choices uses a limited, approximate, simplified **model** of the situation that allows decisions to be made and actions to be taken.

Studies of managerial behaviour find that managers spend very little time actually making decisions, with most of their time meeting people and executing "managerial performances" (Cyert and March, 1992, p. 236). In this way, decisions can be considered "less a theory of choice, than a theory of attention" (March, Simon and Guetzkow, 1993, p. 4), with meetings and interactions producing a form of *negotiated knowledge* (Hans de Bruijn and Martijn Leijten, 2008, p. 92) regarding desired outcomes and how they are to be achieved. This leads towards a view of decision-making takes place across a network of different parties.

2.2.2 Relevance to this research

For a strategic decision, such as the procurement of new trains in the UK, there is an *expected* way of making decisions, which does not involve consulting oracles (March, Simon and Guetzkow, 1993, p. 17), but does include timetables, contracts, response templates, and highly detailed requirements documents. A rigorous and detailed analytical process, governed by procurement legislation, reflects an expectation of decision-making as a rational process, that is rule-based, competitive, transparent, and fair. Rationality is embedded and visible in the documents and processes.

However, these decisions involve significant economic and political stakes, which creates a threat to these rational aspirations. The production of new trains involves large economic value, with, for example, new Crossrail trains costing more than £1Bn. Many stakeholders are involved directly in the strategic decision, and more have an indirect interest in the new trains, railways, and the services that they provide. New trains are more than mass-transit services; they can revitalise areas of a city, reduce congestion and pollution (Short and Kopp, 2005, p. 366), create employment, act as symbols of pride, and more. A heightened political environment can surround such strategic decisions and rational decision-making processes can prove to be "quite defenceless in the face of power" (Flyvbjerg, Rothengatter and Bruzelius, 2003, p. 7). Therefore, the strategic decision to produce new trains should be understood as an "interweaving of both boundedly rational and political processes" (Eisenhardt and Zbaracki, 1992, p. 35). If heavy trains were an unexpected and unintended outcome (King and Crewe, 2014), then they could possibly be explained by the action of power and politics towards outcomes that contributed to an increase in weight, energy use, and emissions.

The main lesson from this literature is recognise strategic decisions as both rational and political actions, involving a complex array of actors and influences. Organisations and managers seek to simplify complexity using models, tools, and information, but such devices are not neutral in this process. A managerial *performance* interacts with influences from other actors, and this collectively produces a form of negotiated action. The idea of a strategic decision as *performance* and the active role of tools is also relevant to the ANT literature that will be explored next.

2.3 Actor-Network Theory (ANT)

The ANT literature was initially accessed because of its history within the field of Science and Technology Studies (STS). As discussed earlier, the application of this ANT to Strategic Decision-Making is the main theoretical lens for the analysis in this research and the contribution to literature. The following provides an overview of the key themes in the ANT literature and its development over time, before summarising its relevance to this research.

2.3.1 Key themes and development over time

ANT reflects a long-standing sociological debate regarding the role of individual agency and social structure to understand behaviour and action. Agency recognises the ability of individuals to act independently and make their own choices. Social structure recognises the influence of class, religion, gender, ability, and other *social forces* or factors. Rather than taking a position on either side of this dualism, ANT's approach is to replace "…the two traditionally separate notions of agent and network by the single one of agent-network" (Callon, 1998, p. 9). Latour describes ANT as a *sociology of associations* (Latour, 2007, p. 9), with various entities enmeshed in relationships. ANT effectively proposes an ontology that replaces *actors* with *actor-networks* to explain action.

Some entities within this network can be described as human or social, and others could be natural, technological, or some other non-human / non-social category. This can lead to the criticism that established concepts "of class, race, and gender – disappear" (Sovacool and Hess, 2017, p. 721). However, that is not the intent, rather ANT simply argues that "the social should not be privileged" (Law, 2012, p. 107) when viewing human and non-human actors. The actors in ANT may be more accurately described as *actants*, derived from semiotics, to adopt a "less-anthropocentric term" (Bennett, 2005, p. 446) and move away from the human-centric word *actor*. In this thesis, the word actor will be used throughout to align with more general usage, but in keeping with ANT, it should be recognised that actors can be human and non-human.

This recognition of non-human actors is a controversial aspect of ANT, but Latour points out that when we say that "kettles 'boil' water, knives 'cut' meat" (Latour, 2007, p. 71) we are recognising that the action is performed by the human-kettle and human-knife complex. For ANT, action is not only limited to what 'intentional', 'meaningful' humans do, rather it is "a distributed achievement, emerging from associations between human and non-human entities (the actor-network)" (Müller and Schurr, 2016, p. 218). In fact, for ANT there is literally "nothing but networks" (Latour, 2017, pp. 4–6), with actor-networks contained within other actor-networks, because actions can be composed of other actions, and so on.

The word *network,* as used in ANT, is meant to convey a supple meaning, rather than the modern use of the word, like a computer network. This is not a network with wired connections transmitting data without any changes introduced. Rather it is more like Deleuze's and Guattari's (1988) philosophical term *rhizome,* and the associated concept of assemblage, which sees fibrous connections and "social formations as temporary aggregates of objects and people" (Davies, 2012, p. 276). Like Actor-Networks the concept of the assemblage is not straightforward to define (Müller and Schurr, 2016, p. 219), but it also locates heterogeneous entities together, and it is this "arrangement that creates agency" (Müller, 2015, p. 28). Although there are many similarities between ANT and assemblage theory (Müller, 2015, p. 30), with terms often used interchangeably, assemblage theory is more of a "philosophical perspective" (Müller and Schurr, 2016, p. 219) with ANT offering, perhaps, a more tangible theoretical 'tool' beneficial in the process of understanding the actors, agents and networks of strategic decision-making (as will be used in the chapters to follow).

A critical intent, common to both Actor-Networks and assemblages, is the flexibility in arrangements, which means they are **capable of "acting in different ways depending on their configuration"** (Callon, 2006, p. 13). This fibrous connectivity can lead to a series of "transformations" (Latour, 1998, p. 15) that can "reconstitute identities" (Callon, 1998, p. 17) – with changing relations rebuilding and changing identities. An Actor-Network should be considered as a verb instead of a noun, an active "site of struggle" (Law, 1992, p. 385) and dynamic development. This active development can involve a "successive enrolment of others to form what amounts to a single will across the network" (Allen, 2009, p. 204), with the actor-network as the ontological object with agency. Entities enrolled into the network may represent others, but "representation is fallible, and it cannot be foretold whether a representative will successfully speak for (and so mask) what it claims to represent" (Law, 1992, p. 388).

This networked and distributed approach leads to a common criticism that ANT is "too abstract" (Sovacool and Hess, 2017, p. 721), with difficulties in defining where actor-networks begin and end. An actor in ANT is a more "anonymous, ill-defined and indiscernible entity" (Callon, 1999, p. 182). However, with this approach an actor is simply "something that acts" (Latour, 2017, p. 7) and "if an actor makes no difference, then it's not an actor" (Latour, 2007, p. 130). Actors are included if they "are able to make their presence individually felt" (Law, 2012, p. 125). Fundamentally, ANT is an **approach and toolkit** that stresses the need to avoid "the social scientist's powerful gaze and methods" (Latour, 1998, p. 19), with its ever-present risk of imposing pre-conceived answers upon a situation.

To manage the potential open-endedness of networks the Aristotelian idea of the *unmoved mover*, or primary cause, is valuable. This identifies one entity within the actor-network as a *Prime Mover*. This entity may have been instrumental in assembling the network: defining the problem, engaging the interest of others, and allocating roles (Callon, 1984, p. 6) as the network develops. The identification of a Prime Mover helps to give some descriptive *colour* to the analysis but the "attribution to one actor of the role of prime mover in no way weakens the necessity of a composition of forces to explain the action" (Latour, 1999, p. 182).

2.3.2 Relevance to this research

Applying some of these ideas to this specific research problem, I propose that a train is a *technological object* (Law, 2012, p. 109) that is neither "inevitable nor static…[but is] the product of complex relations of alliance and conflict among divergent actors and their interests" (Sovacool and Hess, 2017, p. 720). A train is a technological object, and it is also an actor-network – a train *acts* and there are different ways in which trains can act.

Different actor-network configurations of entities could all be recognised as a train, but they would have different attributes and characteristics that reflect their different configurations. Trains, and other entities, "acquire their attributes as a result of their relations with other entities" (Law, 1999, p. 3) and there are many different actor-networks that can act as trains. An outcome of heavy trains reflects a specific configuration of entities in an actor-network, that has an attribute of excess weight. Weight is one attribute of an actor-network that acts as a train, but weight is *entangled* with other attributes, such as comfort, safety, and acceleration. There is a *material configuration* of the train, with components that contribute towards its weight, such as the wheels, engine, glass windows, steel bodies, aluminium doors, passenger seats, and so on. However, there is also a *semiotic configuration* of the train, with *meanings* attached to different configurations of material components. For example, as discussed in Chapter 1, trains like the Pendolino are 2.7m wide, whereas the Japanese Shinkansen trains are 3.3m wide. A width of 2.7m is an attribute of that train, but to explain **why** it is this width requires an understanding of the Victorian architecture of the UK rail network and the action of the loading gauge upon the train.

Therefore, this research considers the actor-network that performs as a train to be **a material-semiotic configuration of physical objects that are caught up and shaped in relations that carry meanings** (Law and Allaskuvla, 2019). Weight is one of many attributes, and there are many possible configurations of actor-networks that can act as a train.

An outcome of increased weight was not inevitable, rather it was one outcome among "many conditions of possibility" (Mol, 1999, p. 75). Different possibilities, or conceptions, of trains, reflect a confrontation between competing "socio-technical worlds that are struggling to exist, at the expense of other socio-technical worlds" (Callon, 2006, p. 39). At some point a *convergence* (Tim J. Newton, 2002; Young, Borland and Coghill, 2010; Anderson, 2012) towards one configuration can arise, as the most suitable, most appropriate, convenient, or '*best'*, **response to the world in which the actor-network is located.** To understand how strategic decisions could produce heavy trains requires an understanding of this *world* in which they were produced. The idea of a decision-laboratory will be developed in more detail shortly, but this reflects the 'world' in which strategic decisions to produce new trains take place.

This can quickly become conceptually complex because, as discussed earlier, with ANT there is nothing but networks. For example, in the modern railway there are typically competing bid teams in a competitive procurement contest. Each of these bid teams is an actor-network and they are also producing their competing proposals of trains, which are actor-networks. Additionally, when the train finally enters operational service, it will form an actor-network with the surrounding railway infrastructure, the passengers, and more. With an ANT perspective, the tunnels and other entities cannot be considered as somehow external to the action to produce new trains, because they actively shape the configuration of the train, which must be able to travel safely through this infrastructure. In addition to this physical infrastructure, there is a network of social relations which also act upon the body and meaning of the train. For example, when new trains and similar large projects are developed, they are often described, or justified (Flyvbjerg, Rothengatter and Bruzelius, 2003, p. 65), in terms of their contribution towards economic growth, which will act upon the timetables, station stops, required speeds, carrying capacities, and more.

To conclude, weight is one attribute among many of different material-semiotic configurations that can all perform as trains. Heavy trains were not inevitable but reflect a convergence towards specific configurations with an attribute of excess weight. This research will investigate how this convergence has happened. This is unlikely to discover a perpetrator who demanded, "make sure those trains are heavy!" The desire for a smoking gun does not fit well with ANT's distributed view of agency.

ANT will be applied to Strategic Decision-Making to understand the production of new trains and the outcome of heavy trains. Actor-networks present an interesting way to understand technological objects that act as trains, and the actions that produce new trains. The next section will describe the theoretical model that will be used in the rest of this research.

2.4 Theory to understand the production of new trains

Using insights from Actor-Network Theory this section describes the theoretical model used for subsequent analysis to understand the strategic decisions to produce new trains, and the phenomenon of heavy trains.

My starting position is that a train is a technological object that, in ANT, is an actor-network. I view this technological object and technology as "neither inherently 'Good' nor 'Bad' – but nor is it neutral" (Kranzberg, 1986, p. 545), rather technology can be defined as "a family of methods for associating and channelling other entities and forces, both human and nonhuman" (Law, 2012, p. 109). A train "may be seen as a product or an effect of a network of heterogeneous materials" (Law, 1992, p. 381) and there are a multitude of ways to arrange resources to act as a train.

The heterogeneous resources brought together to act as a train might include a human train driver, for example, or they might not. The early steam locomotives would include a *Fireman* and *Driver*, but this changed with the advent of trains with electric motors, which replaced coal-fired steam power. The human who controlled the train in this network was now a *Motorman*. The presence of only one person in the cab controlling the train created a safety risk and “led to the provision of a dead-man’s handle” (Robertson, 2005, p. 17). This technology would apply the brakes if there was a problem with the *Motorman*, whereas the *Fireman* would perform this action previously in the earlier configuration of a train using steam produced by burning coal. With some trains, like the automated Docklands Light Railway in London, there is no need for any onboard driver or controller. The socio-material network that acts as **a train has a fluidity of relations** (Law and Singleton, 2005, p. 338).

There are many possible actor-networks that can act as trains, with all having different attributes. Some will carry more people, cost more to run, provide a more comfortable experience, be safer, faster, and so on. Some will be heavier than others, as measured by kg per seat – the entry point for this research.

With ANT, a train is an actor-network, but a train is also produced by actor-networks. At Rainhill there were Triallists who had entered their locomotives into the competition; for Thameslink and Crossrail there are global manufacturers with their trains represented in proposals. Each competitor will have a different configuration of partners, processes, and other entities within their actor-networks. This is easily recognisable in modern procurements, which often involve bid consortia that might include train manufacturers, suppliers of finance and specialist organisations, in addition to existing relationships with companies that provide components, such as seats, air conditioning units, engines and more. In the case of Thameslink and Crossrail, in addition to the competing bidders and their consortia, the production of new trains also involves government bodies such as the Department for Transport, Transport for London, and Network Rail who own and manage the UK rail infrastructure. The infrastructure on which the train operates also shapes, and acts with, the train – the technical infrastructure, type of signalling, and so on, as well as the natural environment of hills, gradients, trees, leaves, and more.

The action to produce the new trains is also acted upon by procurement legislation and guidelines from the EU and UK, which may influence the timetable, format of the process, and other factors. Other standards and legislation may act upon the trains so that, for example, accessibility for Persons of Reduced Mobility (PRM) is improved on the new trains.

A complex picture of actor-networks acting upon other actor-networks can easily lead to confusion and so, to address this, I introduce a metaphor here to help explain the developing theoretical model. Firstly, I will explain two metaphors that were considered, but ruled out.

The metaphor of a **stage performance** was considered, as it involves actors in the foreground with major parts, and a wider cast in the background with lesser, but still important, roles. The wooden and steel set, electrical lighting, costumes, and other apparatus all contribute towards a collective performance, which is changed if, for example, different actors play different roles, the lighting changes, or different sound effects are used. There is usually a script, that provides a common endeavour being pursued collectively, but performances from night to night are not replays or perfect copies, because there are always variations, which makes them recognisably similar, but each is unique.

The second metaphor to be considered, but ruled out, was a **factory**, involving the assembling of various components into a whole, with humans, machines, processes, and other entities all interacting towards a final output. Different human operators can be brought into the production, as shifts change. Machinery parts may be replaced through maintenance and repair. Some aspects of the process may appear to be more important than others, but all are necessary to produce the outcome. The process may be designed to minimal variance but there are still acceptable tolerances for variation.

However, these were both dropped because I did not feel that they captured the idea of **experiments** taking place at Rainhill and **proposals of trains** being produced for Thameslink and Crossrail. **Experiments and proposals both capture an idea of discovery and exploration in this action**, which is not associated with the factory metaphor, and, although a stage performance can convey this, it did not feel like an ideal fit.

Instead, the metaphor of the **laboratory** is used to help understand the strategic decision to introduce new trains. A laboratory suggests **a staged and simulated environment, which is not real life but seeks to represent or resemble it in some way**.

The competitors at Rainhill are not asked to run the real route between Liverpool and Manchester, which was not complete at the time, but they are taking part in experiments, with a test track to simulate the real railway. There are no tunnels on the test track, but competitors are asked to make their locomotives no taller than 15 feet because the real railway will have tunnels 16 feet high. They are given weight limits for their locomotives, based upon an assessment of what the track can tolerate, and the test track allows this tolerance to be verified.

A 7,000-page **proposal of a train**, submitted in response to the Crossrail and Thameslink competitions, is not as evocative an image as the exotic creatures of Rainhill. However, these proposals, or *proposed trains*, are also created in response to stipulations and conditions embodied in a Train Technical Specification and other documents. The proposed trains do not run through real tunnels in London, but they must demonstrate they can safely navigate the infrastructure, as represented in computer models. Competitors are given weight limits for the trains, not because of the fragility of the track, but to achieve environmental goals and reduce maintenance costs.

Both Rainhill and the later actions involve **modelled railways** on which competing trains are tested and trialled in numerous experiments. **An outdoor laboratory in 1829, and a laboratory that is dispersed across physical and digital space in the 21st century.**

There are some limitations to the metaphor of the laboratory. For example, laboratory experiments can value the discovery of contrary evidence that potentially disproves a theory. It is unlikely that the production of a ‘bad’ train would be appreciated, given the stakes involved, even if it might improve our understanding of what does not work! The production of new trains does not involve scientists speculating theoretically about a world *out there*. Instead, it involves actors and practices producing a form of technology (trains), but this is not a factory producing the same widget again and again. There is a fundamental uncertainty regarding the exact form that this technology should take. The experiments at Rainhill capture this uncertainty and the exploratory nature of this action. This **metaphorical laboratory is a specialist place that exists for a specific purpose** – to produce a best guess, or estimate, of a train to operate in the future on the railway of interest. Rainhill simulated the L&MR, and the Thameslink and Crossrail procurements did the same for their railways. To differentiate it from its more traditional use I will describe this place as a metaphorical ***decision-laboratory*** – like a traditional laboratory, but with important differences that will be explored. The next part of theory development will consider what is taking place within these *decision-laboratories*.

At Rainhill and the two later procurements there are trains taking part in experiments to determine which should be chosen to operate on the respective railways in the future. At Rainhill we have *The Rocket* and other competitors, whereas in the recent procurements we have *proposals of trains* that are represented in documents and other forms submitted by Siemens, Bombardier, and other competitors. Although they are in different physical forms, for the purpose of theory development I describe these as the same type of thing: I describe them all as *propositions of trains*. The concept of a *proposition* is explored by Isabelle Stengers (2011) in her analysis of the work of Alfred Whitehead (1929), the mathematician and philosopher. A *proposition* is linked to the process of abstraction. The trains discussed in the introduction to this thesis (Chapter 1) are all **abstractions of the trains that will run in the future**. Abstractions would be of no use if they were projected "upon a mute reality" (Stcngers, 2011, p. 399) and that is the purpose of the experiments at Rainhill, and the many assessments in the recent procurements: to **test and evaluate these propositions**. However, these abstractions are not being tested in their future real-world environment, but in the abstracted and modelled environment of the laboratory. The experimental environments are part of this abstraction process because they are themselves abstractions of reality. The track at Rainhill is not the real track between Liverpool and Manchester. The competitors for Thameslink and Crossrail do not run real trains on the real route to demonstrate their ability to meet timetable commitments, instead computer models are used for the route and the trains.

With this theoretical model we now have *propositions* of trains that are produced in *decision-laboratories*. The propositions of trains can still be described as actor-networks – material-semiotic networks – even though *Rocket's* wooden wheels are more evidently material than those of later trains represented in computer models and engineering specifications. The computer model of a train, produced for Thameslink and Crossrail, still acts as a train, even when it is running on the computer model that represents the track and infrastructure.

Within the decision-laboratories there are different actor-networks engaged in the production of different propositions of new trains. At some point a winning proposition is identified and selected *to become*, in the future, a train operating on the railway and carrying passengers. This future train is described in this research as the *realised train,* to differentiate it from the earlier *proposition* of a train. A diagram of this *process of becoming*, that produces a new train, is shown in Figure 2.1 below.

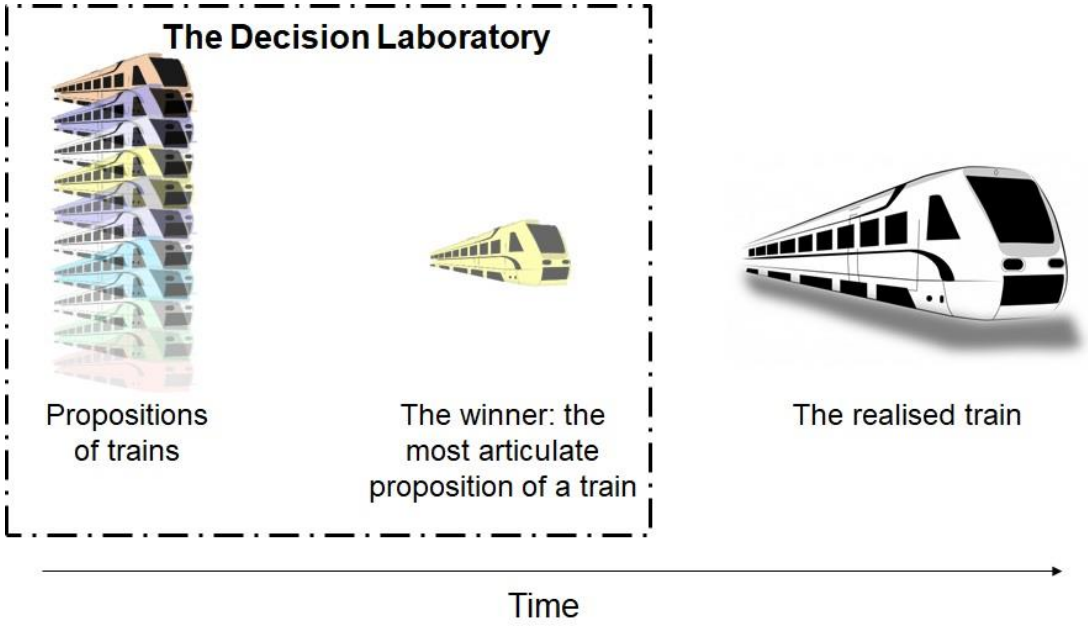


Figure 2.1 Theoretical schema of the production of new trains

This schema (Figure 2.1) identifies *propositions* of trains produced in a *decision-laboratory*, with one *proposition* (in this case) selected as the winner. At some point later, this winning *proposition* becomes the *realised train* that transports passengers. A dotted line surrounds the decision-laboratory and is meant to convey porous walls, and a ‘place’ that is not removed from some outside world. The diagram describes the winning proposition as *the most articulate proposition of a train* – and this will be elaborated next.

In his study of scientific practice, Latour proposes the concepts of *articulation* (Latour, 1999, 2004) and *propositions* as an alternative to the use of scientific *statements* made about the world. Where statements can be either be true or false (Popper, 2002), propositions are not true or false, but they can be more, or less, *articulate*. Statements about a world *out there* will always face the gap between the world of language and the real world, and this gap “shows no sign of being filled”

(Latour, 1999, p. 148), because our symbols, thoughts and representations will never be the thing (referent) to which we refer.

The dictionary definition of *articulate* can mean the ability to communicate clearly, but it can also be understood in terms of joints and connections, like an articulated lorry. In this thesis the word articulate acts as both a verb and an adjective. There is an **active process of articulation** that introduces connections to other ideas and things that is taking place in, and with, the decision laboratory. The propositions of trains can also be said to be becoming more articulate, in that they increasingly express and communicate the best guess of a train within the decision-laboratory. **The decision-laboratory is the place in which propositions are articulated.** Some propositions will be more articulate than others. The winning proposition is the most articulate.

So, we can say that ***Rocket*** **won because it was the most articulate proposition of a train performing at Rainhill**. It was connected (articulated) to, and with, the stipulations and conditions specifying weight limits, and so would not damage the track; it could pull the specified test loads; it consumed its own smoke by burning coke; and so on. The other competitors with their different propositions of locomotives were part of the same experiments, but they did not perform so well – they were not as articulate with respect to these local conditions.

The *Novelty* proposition did not have a tender car and was therefore much lighter in weight than *Rocket*. However, weight was only part of what made an articulate proposition. *Novelty's* lightweight design may have connected (articulated) well with the fragility of early railway track, but it was not able to travel the required distance, while carrying specified loads. Even when the judges modified the stipulations and conditions to calculate *Novelty's* required load, it was still unable to perform for the required 10 laps of the test circuit. *Rocket* won because it was the most articulate proposition of a train at Rainhill. *Rocket* later *became* the realised train operating on the Liverpool & Manchester Railway.

Siemens and Bombardier also won because they were the most articulate propositions of trains for the Thameslink and Crossrail procurements, respectively. Chapter 6 will show that both competitions were interrupted and extended, and, in the case of Crossrail, the conditions were changed during the process to remove the requirement for private financing, and to reflect the UK Government's updated guidance to public sector procurement. The propositions of trains were shaped in their respective decision-laboratories, with new articulations to demonstrate local supplier use and support to local economies. Siemens and Bombardier were awarded the contract because they provided the most articulate propositions of trains within the decision-laboratories that existed for the Thameslink and Crossrail procurements. These propositions of trains *became* the Class 700 and Class 345 realised trains.

The most articulate propositions are produced within, and by, the decision-laboratory experiments taking place at Rainhill and the recent procurements. This is not same as saying these are the best trains for their railways, rather they are essentially a **good guess** of the best trains for these railways. Judgment of success or otherwise is in the "hands of later users" (Latour, 1987, p. 59) and the winning proposition of a train may or may not be ideal, when it is exposed to operation in the real world of rain, hills, angry passengers, and congested networks. *Rocket* is viewed by most as a success, but more time is needed to judge the other trains.

To summarise, we have propositions of trains, that are articulated in a decision-laboratory. The most articulate proposition of a train is selected as the winner and will become a realised train at some point in the future.

The final piece of theory development focused upon understanding the actor-networks involved in the action to produce articulate propositions of trains in the decision-laboratory. A networked view of action needs to recognise this as "a *collective* process" (Latour, 1987, p. 29) and avoid seeing some inner core of actors in the foreground, with a surrounding, relatively passive background. Therefore, to understand the collective action taking place within the decision laboratory to produce propositions of trains I propose to use Latour's (1999) five loop model (Figure 2.2 below). This model helps to understand how the action can reach out to enrol and engage other groups to make the growing network stronger.

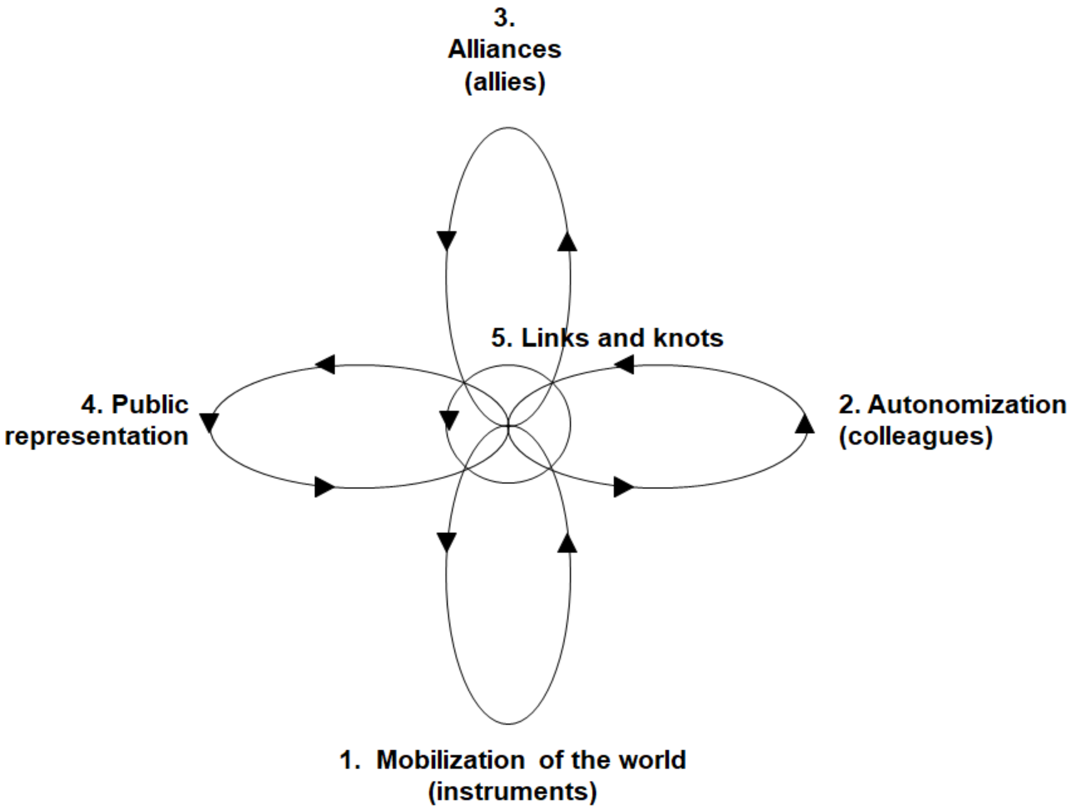


Figure 2.2 Theoretical model of five circulating loops used in this actor-network theory analysis of heavy trains

Source: (Latour, 1999, p. 100)

This model was originally developed within the study of scientific practice. In contrast to a model of science as an activity that is somehow removed from society, this model **placed it firmly embedded** in social systems. Science is not practiced in sterile and socially isolated laboratories by humans and instruments, that are somehow removed from the social world.

This theoretical model is applied in this thesis to understand the action of articulation that produces propositions of trains within a decision-laboratory. This action is described across a circulatory system of five loops – "each of the five activities is as important as the others, and each feeds into itself and into the other four" (Latour, 1999, p. 99). These activities are described next.

Mobilisation of the world captures the ways in which the complexities of the real world are *transformed* into evidence, theories, numbers, tables, and other forms. This transformation makes them "transportable, reproducible, and diffusible" (Callon, 1984, p. 14), so that they can *represent* real world complexities within this actor-network. This inherently involves a process of abstraction and simplification to achieve the goal of bringing the world into the action. This can involve techniques such as surveys, questionnaires, consultations, and many other ways to convert things *out there*, into a form that can then be mobilised within the action. For railways this could include, for example, all the ways in which the desires and needs of future passengers are measured and assessed – using surveys and interviews – and then mobilised as evidence to shape aspects of new train design.

The second loop, *autonomisation (colleagues)*, captures the “ways in which a discipline, a profession, a clique or an ‘invisible college’ becomes independent and forms its own criteria of evaluation and reference” (Latour, 1999, p. 102). The entities and activities associated with this specialist group can be recognised as an *autonomous* group within a wider network. This captures the “enrolment of support” (Phillips and Smith, 2018, p. 12) for an idea, concept or action within a distinct specialism. An actor-network is made stronger when a group of experts agree and come together. This loop includes colleagues, professions, disciplines, and institutions that all help to provide resources, status, and regulations that identify a group of individuals as specialists. Railways have been identified as a distinct profession since the early 19th century (Chapter 5). The modern production of trains is part of the wider railway and engineering network, and rolling stock is a specialist community of interest within this group. The actor-network to produce new trains is theoretically open to any organisation that responds to the first call for interest. However, those entities without recognised specialist skills are removed early in the process of network formation to produce new trains.

The third loop, *alliances*, is about enrolment of support beyond the immediate activities of interest. Allies beyond the specialists within the second loop help to make the network more robust, including helping to rebuff those “who support competing outcomes” (Young, Borland and Coghill, 2010, p. 1209). For the railways, and the production of new trains, alliances can be formed because of the economic opportunities supported by the railways. This can draw local employers and employee groups into the network, to support one outcome over others, or to ensure that the action makes progress and is not stymied by other interests. Environmental NGOs are potential allies with an interest in the emissions and energy performance of trains, as well as generally supporting public transport.

The fourth and final outer loop, *public representation*, includes the public, media, “reporters, pundits and the man and woman in the street” (Latour, 1999, p. 105). The fourth loop represents a movement towards becoming “part of the discourse in the public domain” (van Eijck, 2010, p. 2434). People who travel by rail for commuting and other purposes are within this loop. Organisations such as Transport Focus are an organisation that *represent* the interests of passengers within the action to produce new trains. Occasionally rail creates news in the general media for positive and negative reasons – including ticket prices that increase by inflation each year, the new high-speed rail link (High Speed 2), the launch of new trains, and more.

The centre, or *links and knots*, represents the “pumping heart…a conceptual core” (Latour, 1999, pp. 106–107) that holds this circulatory system of heterogeneous resources together. The **loops provide substance and strength, whereas the links and knots at the centre holds the network together**. The links and knots are dynamic, which means that the collection of resources can also change over time. The links and knots do not mean that there is one actor, such as the DfT, at the centre of this action. Rather, the links and knots reflect the concept of: what is a train and this train in particular? Different conceptions of trains and railways can pull in and hold different collections of resources together, and hence produce different trains.

This concludes the review of literature and development of theory. Actor-Network Theory, or *the sociology of translation* (Law, 1992, p. 380; Latour, 2007, p. 106), will be used to understand the strategic decisions that produce new trains. The strategic decision that produces new trains is viewed here as a social process that first produces *propositions* of trains. Various propositions of trains can exist, but they do not yet carry passengers or goods. The most articulate *proposition* is then *translated* and becomes a *realised* train. This **application of ANT to the study of strategic decision-making** will contribute to theoretical understanding of this critical social process. The three bodies of literature reviewed above has found this to be a novel contribution. Strategic decisions to procure new trains are analysed by applying ANT and its network-based view of action as a ‘toolkit’ to understand how an outcome of heavy trains could have been produced.

The next chapter explains the research approach to apply this theory and explore the phenomenon of heavy trains.

3 Research Design: The Story of this Research

This chapter explains **the story of this research** and how the approach developed over time. The final research approach adopted used secondary data sources, such as publicly available procurement documentation, industry data, archival sources, and information accessed via Freedom of Information (FOI) requests. Before describing this final research approach, the following section describes how an ethnographic approach was explored that could have provided access to primary data. The following section describes this earlier development because it was part of the story of this research, and explains why the final approach was adopted, but it also provides some useful insight into the strategic decisions to produce new trains.

3.1 An opportunity to observe a strategic decision

In 2012-13 it was announced that the 35-year-old fleet of Merseyrail trains, operating in the Liverpool City Region, were to be replaced. Merseytravel, the local government body responsible for coordinating public transport across Merseyside, would run a competitive procurement process for the new trains. This presented an opportunity to observe a strategic decision using an ethnographic approach (Flick, von Kardorff and Steinke, 2005) from its very early stages. This procurement was also interesting because Merseytravel were to be the owner of the new trains. This was a new development because most trains are owned by Rolling Stock Operating Companies (ROSCOs) in the modern UK railway.

Contact was made with Merseytravel in early 2013 to explore the possibility of using this procurement as a research focus. Meetings were held with various people within Merseytravel, including the recently appointed Project Director in charge of the procurement, and an in-house solicitor. As the conversation developed the subject of confidentiality agreements arose, because of the need to protect the procurement process and participants. Legal advice was sought from the University of Liverpool and joint discussions were held with legal advisers at Merseytravel. From these meetings and email exchanges a view emerged that it would not be enough for only Merseytravel and myself, as the Researcher, to sign confidentiality agreements. Rather, agreements would need to be signed and approved by all bidders, advisers, and other stakeholders, involved in the procurement. One suggestion that was explored was for Merseytravel to incorporate the confidentiality agreement associated with this research into the wider tender process. When organisations signed up to participate in the tender, they could also agree to participate in the research.

However, this was a high profile and high value strategic decision, with the contract for the new trains estimated at £400M to £500M. For the research proposal to progress, any changes made to allow access for research could not create risk of the procurement process being compromised in any way. Awareness of risk was especially heightened at the time because of problems elsewhere in the railway. Late in 2012, a large competitive tender to run the West Coast rail services, from London to North West England and Scotland, was awarded by the Department for Transport to First Group plc. However, this decision faced a legal challenge (Rowley, 2012) from Virgin Group, the incumbent operator. This led to the cancellation of the award, repayment of nearly £40M of bid costs by the Government to those parties involved, and the need to re-run the competition. This was high-profile news, and clearly illustrated the risks and economic stakes involved in these strategic decisions.

By July 2013 it became clear that anything that modified or compromised the procurement process for new trains in Liverpool created legal and commercial risks. The likelihood of these risks was unknown, and arguably exceedingly small, however, the impact and consequences could be extremely high, as illustrated by the earlier case with the West Coast franchise. Observational research of the procurement was proving too difficult, and so discussions were concluded on good terms with the Merseytravel team.

Four year later, on 16 December 2016, a contract was awarded to Stadler, a Swiss manufacturer, for the supply and maintenance of 52 four-car trains at a value of c. £700M. One of the competing bidders, Bombardier, subsequently launched a legal challenge in the High Court regarding “aspects of Merseytravel's procurement process and the way in which Merseytravel had scored the Bombardier tender” (The Hon. Mr Justice Coulson, 2017, p. 2). Bombardier’s claim focused upon gaining access to confidential Stadler documentation, and other documents relating to the evaluation process. The court ruling found in favour of Bombardier, who were awarded costs, to be paid by Stadler, but there were no further challenges to the contract award. It is probably safe to assume that the documentation, accessible because of the legal ruling, did not provide further grounds for a challenge seeking to reverse the strategic decision. However, this legal challenge by Bombardier further demonstrated the stakes involved within these strategic decisions. Stadler Rail went on to deliver the new trains, which began to enter service in 2020.

When the discussions with Merseytravel concluded a new research approach was developed, which is described in the remainder of this chapter.

3.2 Summary of the research approach

The theoretical model (Chapter 2) described multiple *propositions of trains* produced, or *articulated*, within a *decision-laboratory*. One proposition – the most *articulate* – is identified as the winner and becomes a *realised* train, at some point in the future. The propositions of trains and the realised train all have different socio-material configurations and therefore all have different attributes. The trains in Figure 1.5 (page 15) are realised trains that have been translated from earlier propositions of trains. The design of this research was organised first around this outcome of heavy trains shown in Figure 1.5. However, this chart raised two issues that needed to be addressed. Firstly, the source data that created the chart was not available. Secondly, there were only five trains shown in Figure 1.5, and only the two most recent trains (Voyager diesel tilt and Pendolino electric tilt) showed an increase in weight relative to the earlier trains. With this limited dataset it was unclear if the increase in weight was a wider phenomenon, or just limited to those two trains. Therefore, the research approach needed first to verify the outcome shown in Figure 1.5, and then to determine if heavy trains were a wider phenomenon across UK rolling stock. **The analysis of train weight is documented in Chapter 4.** The research approach for this analysis is described in more detail in Section 3.3 later in this chapter.

The analysis in Chapter 4 provides supporting evidence for the increasing weight of UK trains over time. **Chapters 5 and 6 then investigate how this has happened** by applying theory, developed in Chapter 2, to the translation process that produces new trains.

Chapter 5 applies ANT within an historical analysis to understand the changing configuration of resources that make up the railways and trains over time. The primary goal of this analysis is to establish that trains (and railways) are fluid collections of resources that can be configured, and reconfigured, and can still act as a train. Using the ANT model of five circulating loops (Figure 2.2, page 54) this historical analysis was particularly valuable to explore the fifth loop (links and knots) that is the conceptual core that entangles and holds the loops together. The research approach adopted for this historical analysis is described in Section 3.4 later in this chapter.

Chapter 6 applies ANT using two contemporary strategic decisions to understand the translation process within the decision-laboratory. The introduction of new trains for Thameslink and Crossrail were selected for several reasons. Firstly, the translation process is complete. The realised trains entered operational service, in 2016 and 2017, respectively and so publicly accessible data is available to measure their attributes, such as weight, number of seats, and other characteristics. Additionally, these new trains have been recognised by the railway industry for their lightweight designs and so this provided a valuable contrast to the wider increase in weight explored in Chapter 4. They demonstrate that increasing weight was not inevitable. The research approach adopted for this contemporary analysis is described in Section 3.5 later in this chapter.

Finally, it is important to note a part of the translation process that was deliberately excluded from the scope of this research. For the UK, a decision-laboratory producing propositions of new trains usually involves a complex competitive procurement process that lasts many years. Once a winning proposition of a train is identified during this procurement process it is then translated to become a realised train. Subsequent translations are introduced during contract negotiations, change requests, manufacturing, testing, and more. This later translation into a realised train is excluded from this research because it would have extended the scope significantly beyond what could be achieved within the timescales and resources available to this research. **The focus of this research is the *decision-laboratory*, where propositions are articulated, and the most articulate proposition is identified as the winner.** This was characterised earlier in Figure 2.1 (page 51), with the decision-laboratory surrounded by a dotted line to recognise its porous walls.

To recap, the design of this research approach first wanted to investigate the outcome of heavy trains. ANT theory was then used to produce a rich understanding of the production of new trains within the railways. Each of these steps are discussed in more detail in the following sections.

3.3 Analysis of the weight of British trains (Chapter 4)

The outcome of heavy trains was the prompt for this research and the analysis begins here. Chapter 4 provides in-depth analysis of the weight of British trains before exploring how this could have happened in Chapters 5 and 6. The following section describes the analytical approach used in Chapter 4 to investigate train weight.

The **first step** in the analysis of the weight of trains was to verify the chart shown in Figure 1.5. Reproducing this independently was not a simple task, because there can be many variations in the configurations of the trains shown in the chart. For example, the Pendolino train typically consists of a 9-car trainset, but some were later lengthened to 11-car sets to increase capacity. The chart (Figure 1.5) does not say which Pendolino was used for the analysis. There are many other variations possible across the trains, such as the number of first-class carriages (with fewer seats), availability of dining services, and more. The analysis in Chapter 4 explains how these concerns were overcome. Figure 1.5 also showed Japanese vehicles that were getting lighter over the same period. The data for these Japanese vehicles was reproduced in this analysis, but, as stated in Chapter 1, they were not explored any further in this work because this work is not performing an international comparison of train weight. Data sources for each of these steps are described shortly.

For the **second step**, I expanded the analysis of weight beyond the five trains shown in Figure 1.5. A larger set of UK trains were analysed that included inter-city services, commuter trains, and rural services. This expanded dataset included trains with different forms of traction – electric motors, diesel, and hybrid trains that use both diesel and electric. This second step gave a perspective on the weight of trains across a large and diverse group of different trains. However, this diverse database of trains raised a question of comparability. It was not sensible to compare, for example, the weight per seat of high-speed inter-city trains against, say, trains for rural railways. These trains provide different services and operate on different routes – they all act as trains, but have different attributes. To allow comparisons to be made over time and see how weight was changing I used an approach[2] that focused upon a specific sub-set of trains. This was the third step in the analysis.

For the **third step** I analysed weight across the same type of train: *suburban Electric Multiple Units (EMUs)*. These trains were designed for heavy-duty commuting to move a lot of people in and out of major cities. Different types of this train have been introduced over time in the UK, which provides a good dataset for comparison over time. Trains within this group of suburban EMUs are all powered by electric motors, drawing power from overhead lines using AC power, or third rails supplying DC power. Although there was more commonality in this group of trains, this did not mean that they were all identical, and there was still significant variation across their configurations. For example, some trains operate as 3-car trainsets, some 5-car sets, etc. There can also be variation in the facilities provided on-board, such as toilets, density of seating, air conditioning, electric doors and so on. This variation reflects the dynamic way in which resources can be configured to act as trains – even realised trains providing an operational service can continue to be reconfigured and reorganised through refurbishment processes and other activities.

For the **fourth and final step** in the analysis of train weight I drilled down below the measure of kg per seat, that was used in the original chart (Figure 1.5). This measure was used for consistency in each of steps 1-3 described above. There is no claim made here that this metric (kg per seat) is the best way to judge a train. Rather, it is used through this analysis because it was the metric in the chart that prompted this research. It provides some insight into attributes that are relevant to important societal issues, such as climate change, and that is why it is of interest to this research. This fourth step recognises that weight per seat (kg/seat) is a composite measure consisting of two parts: the weight of the train; and the number of train seats. Drilling down into these two components allowed the analysis to understand if an increase in weight per seat was driven by trains getting heavier, if fewer seats were available, or some combination of both.

Data for the analysis in each step was drawn from publicly available sources (Marsden, 2014; Pritchard, 2018c, 2019b, 2019a) recognised within the rail industry. The latest versions of these publications were used to provide the most recent data.

[2] I owe thanks to Roger Ford of Modern Railways for this suggestion to focus upon commuter EMUs to help with comparability over time.

The data required for this analysis was: the year that the train was first introduced, the train's weight, and the number of seats available across the train. Other characteristics captured for the analysis included the number of cars that make up the train, and information relating to its construction, such as whether the body was made from aluminium or steel, which was used to help understand the changing material configuration of trains over time.

3.4 The production of new trains: historical analysis (Chapter 5)

The earliest trains shown in Figure 1.5 were first introduced to the railway in 1975 when the railway was a nationalised industry, owned and operated by British Railways, whereas the later trains were introduced after privatisation in the 1990s. Given that the trains were produced in different *contexts*, the idea for some form of political economic analysis was introduced into the research approach. However, ANT discourages the use of the "rigid, stuffy word 'context'" (Latour, 1996, p. 133) and so the historical analysis using ANT should not be viewed as context, but is an active part of this investigation.

The historical analysis in Chapter 5 uses ANT to show that **various configurations and collections of resources have acted as trains and railways over time.** Initially the intention was to align this historical analysis with Figure 1.5 and look back to the 1970s, however, as this work progressed the contribution of this analysis to the wider thesis became clearer and the period of analysis was extended. The historical analysis looks back into the history of the railways from the earliest developments through to present day.

I framed the historical analysis by defining **four different eras of the railways**. The first era ranged from the late 18th and early 19th century to the time of the First World War. This was a period of rapid growth in construction and the development of many local railways across the country. The second era was a period of consolidation after World War One. Consolidation into the *Big Four* railways took place, and this period ran just beyond World War Two. The third era began when war ended, and the railways were nationalised. British Rail became the national operator until the mid-1990s when the final era began and runs to the present day. This final era is described as the privatised railway, but it is a mixture of public and private organisations, as will be described later.

To help understand the changing nature of the railways during each of these eras, I analysed **four key descriptive industry variables over time**. The historical analysis in Chapter 5 used time-based charts, to show changes over time in these key variables, as the railways developed across the four different eras. The first of these variables measured the length of railway track over time, which provided an indication of the extent of the physical railway as it grew and matured. The second variable showed industry receipts for passengers and goods, which captured the growing financial income of the railway, and the changing importance of passengers and freight. The third variable measured the number of passenger journeys over time, which reflected the increasing use of the railways by passengers, and the impact of other factors, such as the growth of car ownership. The final descriptive variable showed railway income and expenses, which together provided a perspective on industry profitability and the need for government support.

Across the four different eras I applied Actor-Network Theory to understand the changing railways and production of new trains. Key industry developments during this time, especially legislation, were analysed using ANT to understand the actions and actors that are acting upon and shaping how the railways, and trains, are configured, assembled, and made to act. The descriptive statistics supported this analysis to provide a richer picture of the changing nature of the railways over time. In doing this I was not attempting to produce a definitive history of the railway. Rather, this historical perspective complemented the analysis in Chapter 6 that focused upon recent strategic decisions for Thameslink and Crossrail. The historical analysis applies ANT to show that the collection of resources that act as a train has changed over time and, therefore, it is reasonable to expect that it will continue to change in the future.

For this analysis I used the following data sources. For the industry variables described above I used *British Historical Statistics* (Mitchell and Deane, 1962; Mitchell, 1988) as the primary historical resource, with more recent data accessed via the website of the Office of Rail and Road, which regulates the railways. Historical legislation was accessed using UK Government websites. Any other sources used are always cited in the text of the analysis. To analyse these sources, I used electronic and hard copies for my analysis with use of highlighting to note areas that mapped to the five circulating loops described in Chapter 2 and shown in Figure 2.2 (page 54).

3.5 The production of new trains: analysis of two contemporary actions (Chapter 6)

For the analysis of contemporary strategic decisions to produce new trains I focused upon the procurements of Thameslink and Crossrail. These were chosen for several reasons.

These strategic decisions involved large economic value, with Thameslink estimated at £1.6 Bn and Crossrail £1 Bn in contract value for the winning bidder to supply the trains and associated services. These are not operational or everyday decisions, but reflect the complexity, scale, and importance associated with strategic decisions.

The two separate strategic decisions were selected because they are both seeking to produce similar types of trains. The trains are both electrically powered multiple units (EMUs) providing services to commuters and others travelling in and around London. Although one of the key arguments of this research is that a train is a fluid collection of resources, it does help with the comparative analysis of train weight when similar types of train are assessed. Comparability would be a challenge if, for example, one strategic decision was producing a high-speed inter-city train and the other was producing a rural stopping service. The Thameslink and Crossrail trains are part of the group of suburban EMU trains that are included within the analysis of train weight in Chapter 4.

The Thameslink and Crossrail trains were chosen because they had been delivered into service and were operational on the railway[3]. The Thameslink procurement began in 2008 and Crossrail in 2010, with the trains entering operational service, in 2016 and 2017, respectively. Using the schema developed in Chapter 2, the winning *proposition* of a train had been translated into a *realised* train in the form of the Thameslink Class 700 and Crossrail Class 345 trains that were operational on the railway and carrying passengers. The operation of the trains on the railway meant that data was publicly available to assess their attributes, including weight, number of seats, and more.

[3] Although Crossrail services were only delivering a partial service at the time

Data was not available, from the public sources described earlier, for strategic decisions that had not delivered trains into operational service. One example of this was the production of new trains for Merseyrail. They were excluded because the trains were not in operational service at the time of this analysis, and so it was not possible to see the attributes of the realised trains. As discussed earlier, if an ethnographic approach had been followed then there may have been access to primary data direct from the train manufacturer to assess the weight and other attributes of the trains. However, this research approach used secondary data sources to assess the attributes of the realised trains, and so it was not possible to include the Merseyrail strategic decision.

Another candidate for analysis was the procurement of new trains as part of the Intercity Express Programme (IEP), overseen by the Department for Transport. This procurement began in 2005 for new trains to replace the InterCity 125 and InterCity 225 fleets on the East Coast and Great Western main lines. A contract for c. £4.5Bn was awarded in 2012 to Agility Trains, a consortium of companies including Hitachi. The Class 800 IEP trains began to enter service on the Great Western Main Line in 2017, and the East Coast Main Line in 2019. Partial data on weight and other attributes did exist for the IEP trains. However, the IEP procurement was excluded primarily because they are not suburban EMUs like the Thameslink and Crossrail trains. The IEP trains provide a long-distance inter-city service operating between the main cities of the UK and into London, whereas the Thameslink and Crossrail services generally operate commuter routes around London and surrounding areas. Although this could have provided a contrasting type of service, it would have raised issues around comparability with Thameslink and Crossrail.

To recap, for this analysis I focused upon the strategic decisions to introduce new trains for Thameslink and Crossrail. Both operated in a similar geographical area, moving commuters in and out of London. The two procurements are of similar value, and they take place at similar times. The winning bidders, selected to produce the final trains, were Siemens for Thameslink and Bombardier for Crossrail, which meant there were two different winning suppliers for the analysis.

There was a lot of documentation associated with these procurements. The procurements fall within the scope of the Official Journal of the European Union (OJEU) because of their economic value and use of Public Sector funds. Therefore, they must be listed on the publicly accessible OJEU archives to encourage transparency and fair competition in public tendering. The early part of these procurements began with a Pre-Qualification Questionnaire (PQQ) that was open to many parties potentially interested in bidding. The process then progressed to an Invitation to Tender (ITT) only made available to those who passed the PQQ stage. The documentation associated with these stages provides an insight into what was, and was not, considered relevant to the production of new rolling stock. To analyse the procurements, I used these public documents, which included weightings and scoring criteria allocated to different aspects of the desired trains. Some information, such as bidders' financial information, was unavailable from public sources because it was deemed commercially sensitive. Freedom of Information requests were made to Thameslink (28 March 2017) and Crossrail (22 June 2016), with copies of these requests on page 349 and page 366 of the appendices, respectively. These FOI requests confirmed the document sources used during the procurement and subsequently used for this analysis.

An important source of data was the National Audit Office, an independent UK Parliamentary body responsible for auditing areas of government activity. The NAO completed reviews (National Audit Office, 2014c, 2014b) of these tender processes and the wider rail industry. All documents provided further opportunities to *snowball* references from other sources. Trade press (*RAIL* and *Modern Railways*) was accessed regarding these specific procurements, and for broad analysis of the industry. The perspective of passengers was captured from the trade and national press, as well as research and articles from Transport Focus, the watchdog for transport passengers and road users in the UK.

To analyse these sources, I used the same approach as with the historical analysis for Chapter 5. Electronic and hard copies of documents were used for the analysis with highlighting used to note areas that mapped to the five circulating loops described in Chapter 2 and shown in Figure 2.2.

3.6 Ethics

As discussed in section 3.1, early investigations in this research sought to develop an ethnographic research approach. The challenges of achieving this highlighted the risks that can be associated with this type of research given the high financial stakes and public visibility of these actions. However, these risks were negligible because I changed this approach and moved to the analysis of secondary data from publicly available historical sources. The analysis took place after the decisions have been made and the trains have been delivered.

An application was submitted to the Faculty of Science and Engineering Committee on Research Ethics for research ethics review. This application for research ethics was approved (*reference 2068*) on 22 August 2017 and would carry for five years from that date.

3.7 Summary

This chapter has described the research approach used to apply ANT to understand the strategic decisions that produce new trains, and the phenomenon of heavy trains in the UK.

Analysis first explored the increase in weight across an expanded dataset of UK passenger trains. This provided confidence in the phenomenon of heavy trains and a foundation for subsequent work. Actor-Network Theory was then applied to understand how this could have happened. This was explored first using historical analysis to understand the dynamic collection of resources that have been configured as trains within the railway over time. Two contemporary strategic decisions were then analysed using ANT. The strategic decisions to produce new trains for Thameslink and Crossrail were investigated to understand how these strategic decisions were made. In these two cases the trains produced have been recognised within the industry for their lightweight designs.

4 Analysis of the Weight per Seat of UK Trains

The purpose of this chapter is to prove empirically that trains have got heavier, before ANT theory is used to determine how this has happened in Chapters 5 and 6. This chapter provides a solid empirical base for the analysis by building upon the chart shown in Figure 1.5 that provided the initial prompt for this research.

There are four steps in this analysis, which are illustrated in Figure 4.1 below.

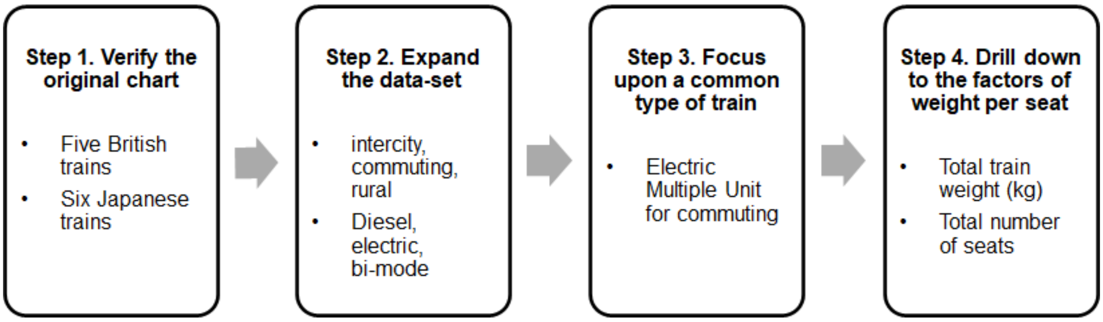


Figure 4.1 Four steps in the analysis of weight per seat for UK trains

The original chart (Figure 1.5, page 15) showed five British trains (Mk III electric, HST diesel, Mk IV electric, Voyager diesel tilt, and Pendolino electric tilt) getting heavier over time. The source data for this chart was unavailable, and so step one of this analysis used publicly available industry data to recreate and verify this chart.

Step two expanded the dataset beyond this group of five British trains and investigated weight per seat across a larger group of UK passenger trains. Step two included trains designed for high-speed inter-city services, commuter, and regional services. This larger dataset raised a question of comparability between the different trains. For example, it is problematic to compare the attributes of a single-car rural rail service to a nine-car high-speed train operating between London and Scotland, because they are designed for such different purposes. This question of comparability was addressed in step three.

Step three took the expanded dataset created in step two and focused, within that dataset, upon a specific type of train – suburban Electric Multiple Units (EMUs) used for commuting services into the major cities of the UK. These EMUs are all electrically powered trains, drawing power from overhead electric lines, or electrified third rails.

Step four recognised that the metric of *weight per passenger seat* is a composite measure consisting of two factors: the weight of the train (the numerator), and the number of seats on that train (the denominator). An increase in weight per seat could be attributable to the trains getting heavier, fewer seats available on the trains, or some combination of these two factors. These two factors were analysed using the datasets created in step two and three.

Before completing these four steps in the analysis, the next section discusses why the weight of trains is important and worthy of investigation.

4.1 Why heavy passenger trains are a concern

For this research heavy trains are primarily a concern because they contribute to climate emissions. In the current UK railway, passenger trains are overwhelmingly powered by electric or diesel engines. A fossil-fuel-powered electricity grid and diesel fuel both produce greenhouse gas emissions and other pollutants.

It could be argued that, if the train is powered by clean and renewable fuel, then weight does not matter. For example, a carbon-free electric grid supply, and the use of all electric rolling stock on a fully electrified network, would produce no GHG emissions. This is a significant challenge in practice, however, with only 38% of the network that is electrified in 2019 (Office of Rail and Road, 2019b, p. 1) and there are ongoing cost challenges to deliver wider electrification. Instead of a carbon-free grid, it might be possible in the future to use hydrogen, which, if stored onboard, could be burnt in a combustion engine, or used by fuel cells to generate electricity to power the train. This technology is continually being improved but it raises various problems, especially regarding how the hydrogen is produced efficiently and stored safely, to say nothing of the costs of converting existing rolling stock.

Greenhouse gas (GHG) emissions for the rail industry within Britain are estimated (RSSB, 2010, p. 21) as follows:

- 63% from traction energy – diesel fuel and electric power used to move trains
- 34% from infrastructure and operations, such as the stations and depots, as well as the lifecycle of rolling stock from production through to disposal
- 3% from staff, offices and services associated with the offices, such as electricity and gas usage.

This analysis by the Rail Safety and Standards Board (2010) reviewed both passenger and freight services, using a comprehensive whole life carbon footprint approach, and concluded that, as shown above, **traction energy is the largest part of GHG emissions for railways in Britain.**

Of the traction energy emissions, passenger services account for 80% compared to 20% for freight (RSSB, 2010, p. 34, Table 5). Passenger emissions were evenly split across diesel and electric traction, whereas freight emissions were overwhelmingly from diesel. One of the main reasons for freight's reliance on diesel is that services often cross parts of the network where there is no electric supply – diesel provides independence from the infrastructure power supply, as fuel is carried with the train.

Train energy efficiency can be improved, using technology such as regenerative braking which can return power to the electricity network, or store it onboard in batteries. Although efficiency can be improved, trains consume energy when they *act as a train*. Many factors contribute to the energy use of trains (Peckham, 2007, p. 14), including providing lighting, heating, air-conditioning and driving styles. Two of the largest factors that explain energy use are common to both diesel and electric trains. Energy is needed to:

- overcome friction and drag; and
- move the train mass

The first bullet point – overcoming friction and drag – is not about weight, but is about moving through the air efficiently, and is most relevant for trains travelling at higher speeds, where "energy used overcoming aerodynamic drag becomes predominant" (Eickhoff and Nowell, 2010, p. 7). For example, "running at 360 km/h rather than 300 km/h increases power consumption of a 200m-long train by around three MegaWatts, or 70%." (Ford, 2017, p. 29). This is because overcoming air resistance "increases with the square of the speed" (Ford, 2017, p. 29), and so the shape and profile of high speed trains is designed to make them move through the air with minimal air resistance, like a plane. Air resistance affects high-speed *maglev* (magnetic levitation) trains, as much as conventional trains, because maglev only eliminates the friction between wheel and rail. Proposals for a hyperloop service using partly evacuated tubes would reduce air resistance, but this is not applicable to trains and other vehicles, which travel through the normal atmosphere, and will encounter normal air resistance.

The second bullet point from above – moving the train mass – is the focus of this research because it relates to the weight of the train. **Excessively heavy trains will require more energy to move their mass and so will produce excess emissions.** Excess weight is relevant to all types of train – inter-city, suburban and rural – because they all must use energy to move their train mass. The relationship between train weight, energy use, and resulting emissions is not simple. For a train to move forward, weight is a “good thing because it provides tractive effort to put down lots of horsepower” (Walmsley, 2018, p. 43), with weight providing adhesion between wheel and rail. Too much weight means too much energy used to move the train “rather than their cargoes or goods or passengers” (*RAIL*, 2018, p. 68). This implies a Goldilocks characteristic of weight – where there must be enough, but not too much!

In addition to increased fuel usage, excess weight will also increase maintenance costs caused by greater damage to the track and infrastructure. Costs will increase for all types of services, but it is amplified for inter-city services, (Eickhoff and Nowell, 2010) because they travel over long distances, using expensive infrastructure designed for high speed use. Increased industry costs contribute towards higher ticket prices for passengers, which reduces modal shift from other modes of transport. This is a further problem because rail can be part of wider transport efforts to reduce emissions, since it is “an environmentally beneficial alternative” (Givoni, Brand and Watkiss, 2009, p. 83) compared to other modes, such as domestic planes and private cars, as shown below in Figure 4.2.

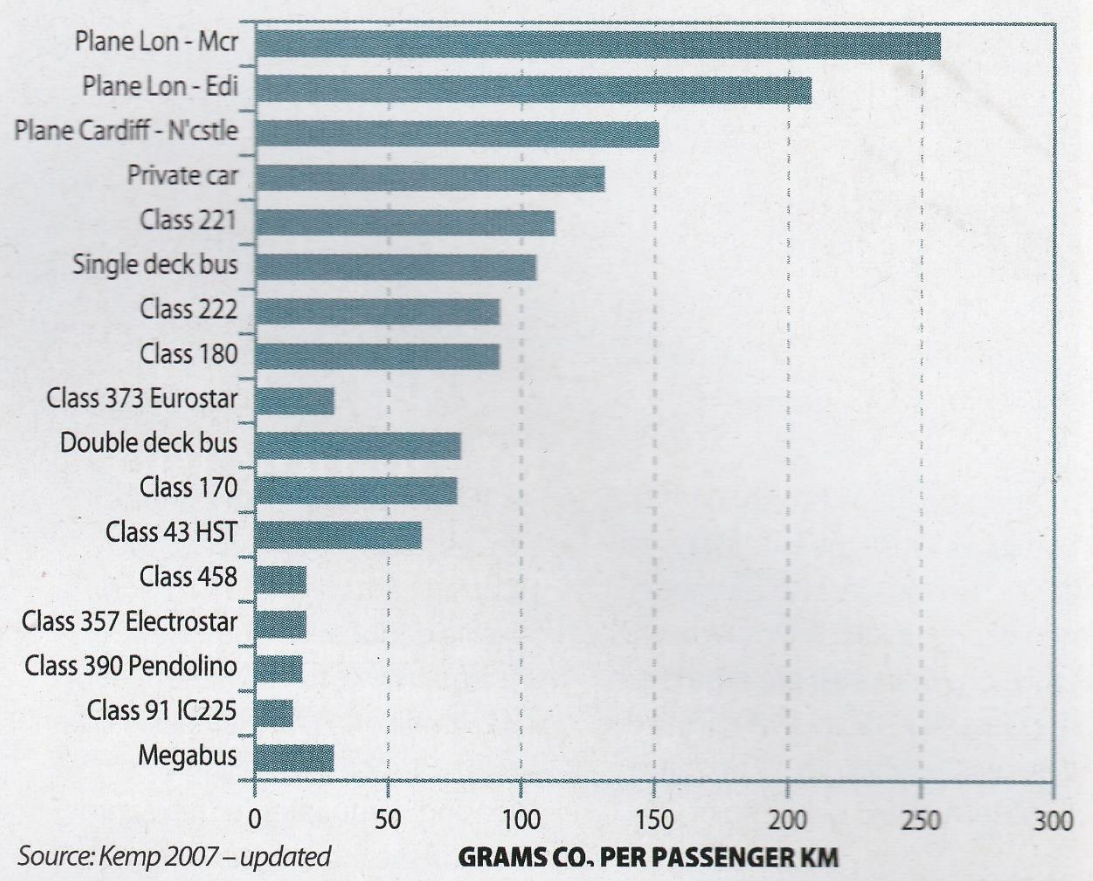


Figure 4.2 Intermodal comparison of CO2

Source: (Department for Transport, 2007, p. 33; Roger Ford, 2019b, p. 31 analysis updated by R. Kemp)

This intermodal comparison of grams CO2 per passenger km (Figure 4.2) demonstrates the important role that rail can play in reducing national GHG emissions. This is especially true if the grid electricity supply reduces its carbon intensity further, which has been happening. The carbon intensity of electricity supply in the UK in 1990, for example, was 770 gCO2 / kWh and this has fallen to 263 gCO2 / kWh in 2017 (Committee on Climate Change, 2018, p. 57 Table 2.2). In addition to rail's advantages in emissions, it is also "the most space and energy efficient way of moving large volumes of people and freight" (Shaw and Farrington, 2003, p. 108), with a road network needing 13 times the space of suburban rail to move the same numbers of people.

Although rail has an environmental advantage over other modes, this advantage will be reduced by unnecessarily heavy trains. Weight is an important factor to explain a train's energy use, and so the remainder of this chapter will explore the increase in train weight over time, using the four steps described earlier.

4.2 Step one: verify the original chart

The original chart (Figure 1.5, page 15) showed data points for five UK trains and six Japanese trains. The source data for Figure 1.5 was not available and so, given the importance of this starting point, the first step in this analysis was to verify empirically this chart.

Although there are only five data points for British trains, there are many ways in which these five trains can be formed and arranged. For example, the HST (High Speed Train) diesel shown in Figure 1.5, consists of diesel locomotives at the front and back providing power, with 6-9 passenger coaches in between, depending upon the expected number of passengers and other operational factors. HST trains could also be configured internally in different ways. For example, a high-density set could have 564 seats, compared to a low density set with 482 seats, even though both might consist of 10 cars (eight passenger cars and two power cars) with a similar weight for the whole train. Some coaches could be configured for first class with fewer seats compared to standard class. There might also be a restaurant car with onboard kitchen, which would have fewer seats than an all-seated carriage. This illustrates the dynamic configuration of physical objects that act as trains. Even when they are realised trains – with a very material form – they can still be reconfigured and reconstituted. The HST diesel discussed above is not a universal and static configuration, and the same applies to the other trains in Figure 1.5.

The source data for Figure 1.5 was unavailable and so it was not possible to know the exact configuration of trains used to create the original chart. Therefore, to verify Figure 1.5 in a consistent and transparent way, the configuration that I have chosen for each train is recorded in this analysis. For example, the HST diesel is shown in Table 4.1 below.

Table 4.1 Configuration of HST Diesel trainset used for step one of this analysis

Vehicle type	Weight (tonnes)	Seats
Class 43 Power Car	70.3	0
Trailer Guard's Standard	33.5	65
Trailer Standard	33.6	76
Trailer Standard	33.6	76
Trailer Standard	33.6	76
Trailer Standard	33.6	76
Trailer Kitchen Buffet First	38.2	17
Trailer First	33.7	48
Trailer First	33.7	48
Class 43 Power Car	70.3	0
Totals for the trainset	**413.9**	**482**

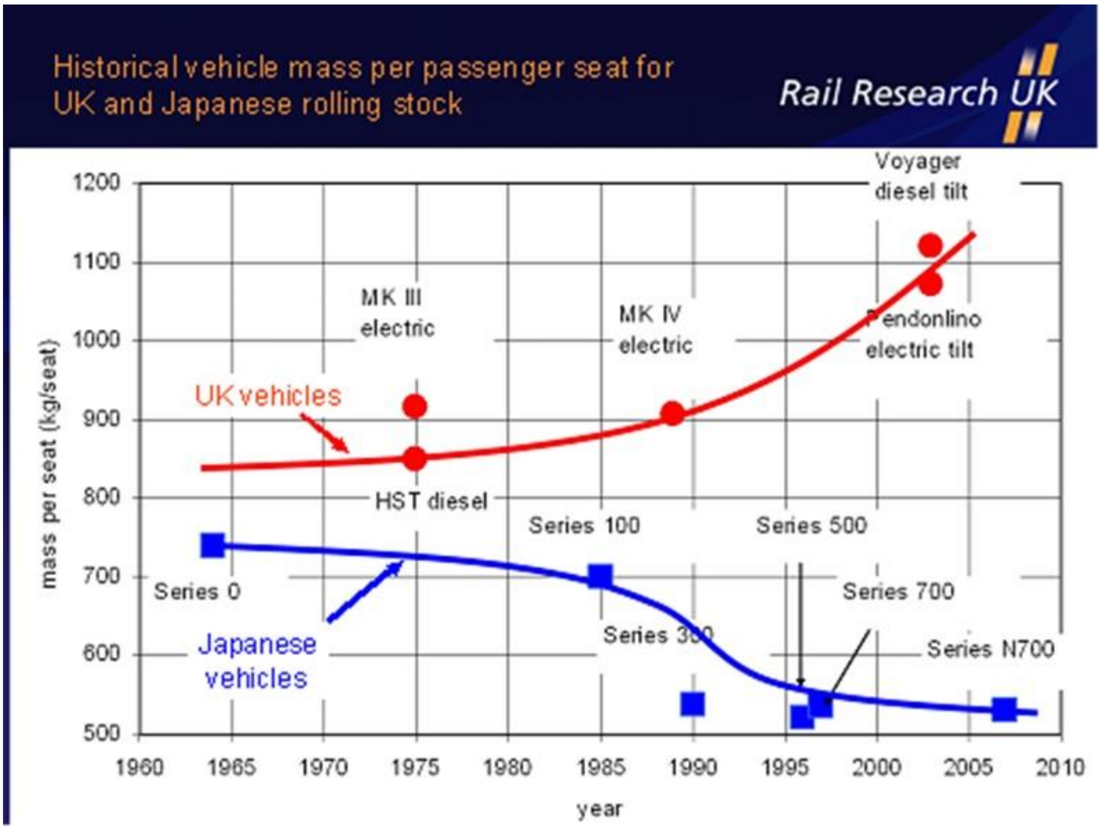
Table 4.1 above shows the weight and number of seats for each vehicle in the HST formation. Industry reference books (Pritchard and Hall, 2013; Marsden, 2014; Pritchard, 2018c; Robert Pritchard, 2019) are used as the source for weight, number of seats, and other data. The HST Diesel, shown in Table 4.1, has 482 seats and a total weight of 413.9 tonnes. This implies a figure of 858.6 kg per seat[4]. This process was repeated for each of the five British trains: HST diesel, Mk III electric, Mk IV electric, Voyager diesel tilt, Pendolino electric tilt. Versions of Table 4.1 are shown in the appendices (page 320) for each of the UK Trains.

The reproduction of Figure 1.5 also needed to consider the data for Japanese rolling stock. The Japanese trains are included to re-create the starting point of this research but, after step one, they will not be investigated any further. The chart values used

[4] Note: rounding may produce marginally different results

for the Japanese trains, and the sources for this data, are shown in Table 9.8 in the appendices.

The results of this analysis are shown in Figure 4.3 below, with the original chart from Rail Research UK shown for comparison.



The original chart: Data from Rail Research UK showing trains getting heavier in the UK (Copy of Figure 1.5)

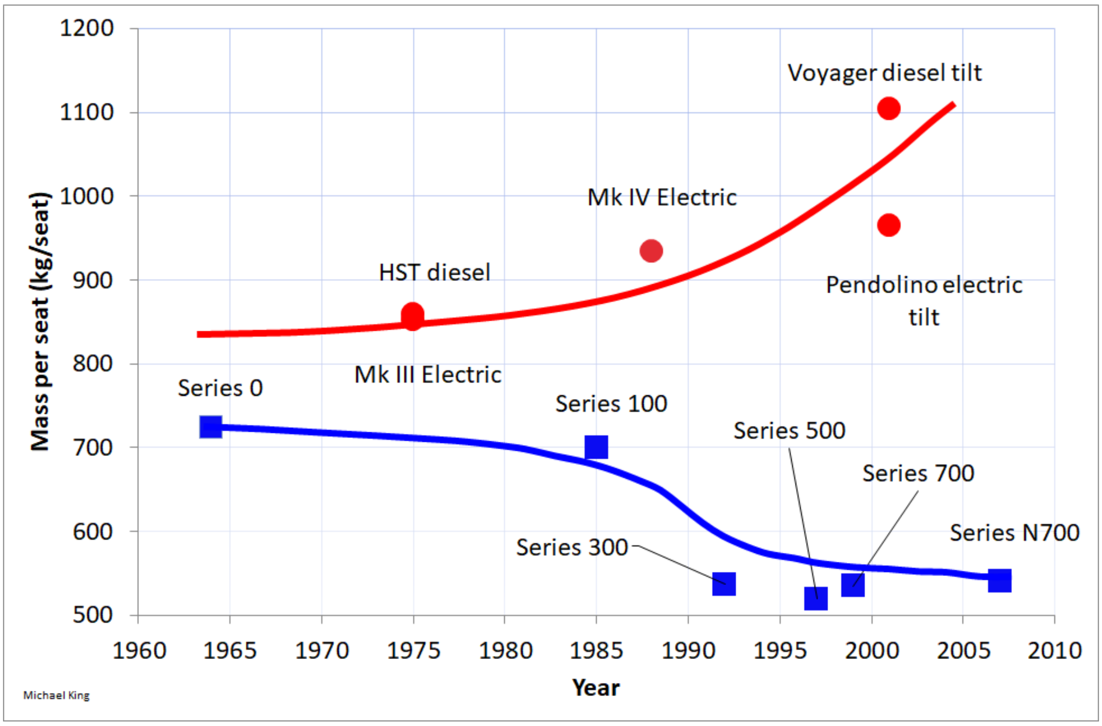


Figure 4.3 Historical vehicle mass per passenger seat for UK and Japanese rolling stock (RRUK chart above, my chart below)

The plotted data shows the year that the train was first introduced into traffic and the weight per passenger seat. As an example, the HST diesel was first introduced into service in 1975 and the weight per passenger seat is 858.6 kg/seat, as per Table 4.1 above. The new chart that I created, shown in Figure 4.3, is not identical to the original chart, but it is close, and differences are likely to be explained by the varying configuration of trainsets as discussed above.

For step one of this analysis, Figure 4.3 provides **support for the increase in the weight of British rolling stock per passenger seat over time**. Step two investigates this further by expanding the dataset beyond this group of five British trains.

4.3 Step two: expand the dataset

The full list of trains used in the second stage of this analysis are identified in the appendix, in Table 9.9, Table 9.10 and Table 9.11 for Electric Multiple Units (EMUs), Diesel Multiple Units (DMUs), and Bi-Modes respectively. The data shown in these tables, including weight, number of seats, and year of introduction, was used in the analysis that follows. The tables in the appendices show additional information on the trains, including the class identifiers that are allocated to different trains in the UK. For example, the Pendolino train has a class identifier of 390, with a sub-class of 390/0 for a 9-car trainset and a 390/1 sub-class for an 11-car trainset.

4.3.1 Descriptive summary of the expanded dataset

All data was sourced from publicly available industry publications (Marsden, 2014; Pritchard, 2018b, 2018a, 2019a) that catalogue various information regarding UK passenger trains. The most recent editions of these publications were used, which only contain trains that are still in operational service. Therefore, this extended database contains trains that are still running, some of which are 30+ years old. Retired classes of trains are excluded from this analysis, although there are some exceptions to this which are discussed later. A class of train is excluded from the analysis if relevant data (seats, weight, year of introduction) is not available. For example, the Class 325 Electric Multiple Unit (EMU) is excluded because it is a Royal Mail parcels train, with no passenger seats, and so it would not be possible to calculate weight per seat. The Class 195/1 (3-car DMU) is excluded because it is a new service and at the time of the analysis there was no data available for weight, however data was available for 195/0 (2-car DMU), and so that was included. The following sections summarise each of the EMU, DMU and Bi-Mode datasets. The first of these, the EMU dataset, is shown below (Table 4.2).

Table 4.2 Summary of the EMU trains in the extended dataset

Item	Count	Min	Max	Average
Number of data points (classes and sub-classes)	91			
Total number of trainsets	2,560			
Year first introduced		1971	2017	
Number of cars in trainset		2	12	4.4
Weight of a trainset (tonnes)		54.8	567.9	171.4
Number of seats in a trainset		82	672	272.2
Weight per seat for trainset (kg/seat)		383.9	1,071.4	629.9

The summary shows that there are 91 data points in total in the EMU dataset. This means there are 91 different classes and sub-classes of Electric Multiple Units (EMUs) in this database. The table shows that these 91 types of EMU represent a total of 2,560 trainsets operating on the UK railway. For example, there are 21 Pendolino Class 390/0 9-car trainsets, there are 61 Class 315 trainsets, and so on. The long list of 91 EMUs is given in Table 9.9 in the appendix.

The EMU trains in this database were introduced into traffic for the first time at various times between 1971 and 2017. The trainset configurations range from 2-car sets through to 12-car sets, with an average EMU consisting of approximately four cars in a set. The weight and number of seats across these trainsets will depend upon the total number of cars in the unit, but an average EMU trainset weighs 171.4 tonnes and has approximately 272 passenger seats. The average EMU in this database weighs 629.9 kg per seat, but Table 4.2 shows that the lightest weight per passenger seat is 383.9 kg / seat and the heaviest is 1,071.4 kg / seat. This gives an idea of the diversity of trains within this larger dataset. Figure 4.4 below shows the trains that account for these two extremes of weight per seat.

Figure 4.4 the extremes of the EMU dataset for kg/seat – Class 465/1 ' Networker' and Class 378/2 'Capitalstar'

Sources: Class 465/1 'Networker' (383.9 kg per seat, shown top) (Marsden, 2014, p. 246); Class 378/2 'Capitalstar' (1071.4 kg per seat, shown bottom) (Marsden, 2014, p. 219)

The train at the top of Figure 4.4 is the Class 465/1 *Networker* that operates as a four-car trainset, with 348 seats and a train weight of 133.6 tonnes, which is 383.9 kg / seat. The seating picture to the right shows a 3+2 layout, with these trains mostly designed for longer distance commuter duties.

The train at the bottom of Figure 4.4 is the Class 378/2 *Capitalstar* that operates as a five-car trainset, with 192 seats and a train weight of 205.7 tonnes, which is 1,071.4 kg / seat. The seating picture to the right shows a longitudinal 'tube style' layout as these trains were mostly designed for operating around the Transport for London network, with more standing room and fewer seats. From an ANT perspective we can see different configurations of resources that act as trains, but with different attributes including different seating and passenger experiences.

There are many other differences between the two trains shown above. For example, the Class 387/2 can operate on electrified infrastructure that uses overhead AC power, as well as parts of the network in the Southern region that use third rail DC power. This added versatility or flexibility to operate on different infrastructure could be expected to mean extra equipment, and so extra weight.

In addition to EMUs there are also DMUs in the extended dataset, with a summary of them shown in Table 4.3 below.

Table 4.3 Summary of the DMU trains in the extended dataset

Item	Count	Min	Max	Average
Number of data points (classes and sub-classes)	57			
Total number of trainsets	1,175			
Year first introduced		1960	2017	
Number of cars in trainset		1	7	2.8
Weight of a trainset (tonnes)		12.5	337.8	119.6
Number of seats in a trainset		21	342	177.7
Weight per seat for trainset (kg/seat)		424.6	1,090.1	673.2

This summary shows there are 57 data points in total in the DMU dataset – 57 different classes and sub-classes of Diesel Multiple Units. These 57 types of DMU represent a total of 1,175 trainsets operating on the UK railway. For example, there are 34 Voyager Class 220 4-car DMU trainsets, there are 94 Class 142 'Pacer' DMU trainsets, and so on. The long list of 57 DMUs is given in Table 9.10 in the appendix.

The DMU trains in this database were first introduced into traffic between 1960 and 2017. The Class 121 DMU is a single car train and Britain's longest serving DMU that was in operational service from 1960 until 2017. It was included in this analysis because it was still referenced in the industry catalogues used as sources for this analysis. The formation of the DMU trainsets in the extended dataset range from single car sets through to 7-car sets, with an average DMU train consisting of approximately three cars. The weight and number of seats across these trainsets will depend upon the total number of cars in the unit, however we can see that an average DMU trainset weighs 119.6 tonnes and has approximately 178 passenger seats. The average DMU in this database weighs 673.2 kg per seat. Table 4.3 shows that the lightest weight per passenger seat is 424.6 kg / seat and the heaviest is 1,090.1 kg / seat. As with the EMU dataset, this gives an idea of the diversity of trains within this larger dataset of DMU trains. Figure 4.5 below shows the trains that account for these two extremes of weight per seat.

Figure 4.5 the extremes of the DMU dataset for kg/seat - Class 165/0 Network Turbo and Class 222 Meridian

Sources: Class 165/0 Network Turbo (424.6 kg per seat, shown top) (Marsden, 2014, pp. 119, 121); Class 222 Meridian 4-car (1090.1 kg per seat, shown bottom) (seats: Marsden, 2007, p. 155, train: 2014, p. 152)

The train at the top of Figure 4.5 is the Class 165/0 *Network Turbo* that operates as a three-car trainset, with 284 seats and a train weight of 120.6 tonnes, which is 424.6 kg / seat. The seating picture to the right shows an example 3+2 layout for standard class seating.

The train at the bottom of Figure 4.5 is the Class 222 *Meridian* that operates as seven-, five-, and four-car formations, but it is the four-car formation that accounts for the largest weight per seat of the DMU dataset. The four-car Class 222 has 181 seats and a train weight of 197.3 tonnes, which is 1,090.1 kg / seat. The seating picture to the right shows standard class seating in a 2+2 layout. The seating layout includes tables, as these trains were mostly used for longer journeys, such as London to Sheffield. Tables within the configuration of a train are valuable to the passenger experience but could be expected to increase weight and possible reduce the space for seating.

The final group of trains within this expanded dataset are the Bi-Mode trains. These new additions to British railways have both diesel and electric traction motors. A summary of the Bi-Mode dataset is shown in Table 4.4 below.

Table 4.4 Summary of the Bi-Mode trains in the extended dataset

Item	Count	Min	Max	Average
Number of data points (classes and sub-classes)	9			
Total number of trainsets	159			
Year first introduced		2013	2019	
Number of cars in trainset		3	9	6.0
Weight of a trainset (tonnes)		138.5	430.3	288.5
Number of seats in a trainset		167	647	399.4
Weight per seat for trainset (kg/seat)		663.4	829.5	722.2

Bi-Modes have only recently been introduced onto British Railways and the summary table above reflects this with only nine data points in total. This means there are nine different classes and sub-classes of Bi-Mode Units in this dataset. These nine types of Bi-Mode represent a total of 159 trainsets operating on the UK railway. For example, there are 36 Great Western InterCity Class 800/0 5-car Bi-Mode trainsets produced as part of the InterCity Express Programme. There are also 14 Class 755/3 *Flirt* Bi-Mode trainsets in Greater Anglia, and so on. The long list of Bi-Modes is given in Table 9.11 in the appendix.

The summary table shows that the Bi-Mode trains in this database were first introduced into traffic between 2013 and 2019. The trainset formations range from 3-car sets through to 9-car sets, with an average Bi-Mode consisting of six cars forming a set. The weight and number of seats across these trainsets will depend upon the total number of cars in the unit, however, an average Bi-Mode trainset weighs 288.5 tonnes and has approximately 399 passenger seats. The average Bi-Mode in this database weighs 722.2 kg per seat. Table 4.4 shows that the lightest weight per passenger seat is 663.4 kg / seat and the heaviest is 829.5 kg / seat. Figure 4.6 below shows the trains that account for these two extremes.

Figure 4.6 the extremes of the Bi-Mode dataset for kg/seat – Class 800/3 and Class 800/2

Sources: Class 800/3 (663.4 kg per seat, shown top) (train: Hitachi Rail Europe; seats: By Geoff Sheppard - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=66554000 ; Class 800/2 (829.5 kg per seat, shown bottom) (train: Rail Business UK; seats: By PeterSkuce - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=86443275)

The train at the top of Figure 4.6 above is the Class 800/3 Bi-Mode that operates as a nine-car trainset, with 647 seats and a train weight of 429.2 tonnes, which is 663.4 kg / seat and is the lightest per seat of the Bi-Modes in this dataset. The seating picture to the right shows an example 2+2 layout for standard class seating. This train operates as a high-speed service for Greater Western Railways (GWR) from London to the South West of England and Wales.

The train at the bottom of Figure 4.6 is also a Class 800, but this time it is the Class 800/2. This operates as a five-car formation and has 302 seats and a train weight of 250.5 tonnes, which is 829.5 kg / seat and is the heaviest weight per seat of the small Bi-Mode dataset. The seating picture to the bottom right shows standard class seating in a 2+2 layout with tables. This train operates as a high-speed service for London and North Eastern Railway (LNER) running between London, the North East of England, and Scotland.

Bi-mode trains include electric and diesel motors within their network of resources that act as a train. This gives the trains an attribute of flexibility, so that they can travel on electrified and non-electrified parts of the network, but the cost of this flexibility should be an increase in weight because of the extra material objects that are carried – the engines, diesel fuel, and other associated equipment.

This completes the descriptive summary of the database of EMUs, DMUs and Bi-Mode trains that form this larger database. There are 91 EMUs, 57 DMUs, and nine Bi-Modes. This gives 157 different classes and sub-classes of trains, compared to the five initial data points used in step one of this analysis. The next section analyses this database to explore further the increase in the weight of UK trains.

4.3.2 Analysis of the larger dataset

The chart below (Figure 4.7) plots the 91 EMUs, 57 DMUs and nine Bi-Modes using the same format as the charts in step one. The horizontal axis shows the year that the unit was first introduced, and the vertical axis shows mass per seat (kg/seat). The different groups (EMUs, DMUs and Bi-Modes) are identified using a blue circle, orange square, and red triangle, respectively.

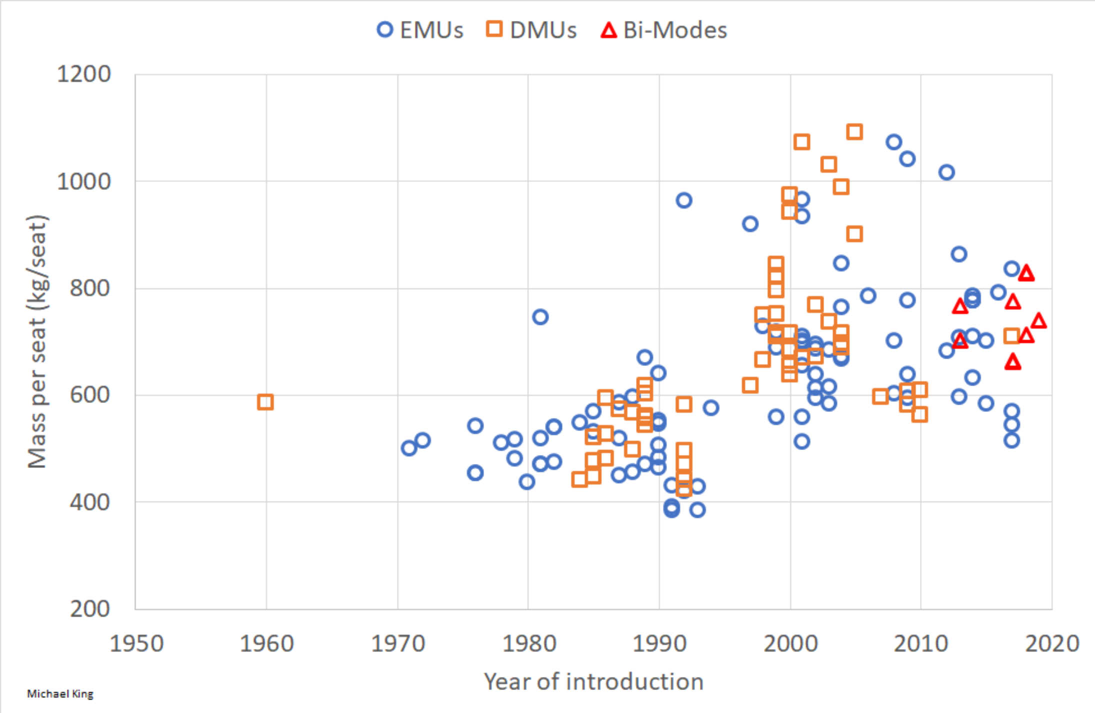


Figure 4.7 Historical vehicle mass per passenger seat for British EMUs, DMUs and Bi-Modes

This trend upwards in the chart provides visual evidence for a weight increase. The EMUs and DMUs introduced in the late 1990s show an increase compared to the cluster of trains introduced earlier. The small number of Bi-Mode trains (red triangles) that were introduced after 2010 show a spread of readings that are heavier (kg per seat) than trains introduced before 1990.

To confirm this visual inspection Table 4.5 below provides a summary of the average kg / seat for trains split by the decade in which they were introduced.

Table 4.5 Average vehicle mass per passenger seat for British EMUs, DMUs and Bi-Modes across the decades

Item	1970s	1980s	1990s	2000s	2010s
Composite of three train types: kg/seat by decade of introduction	493.4	524.0	577.1	747.8	706.5
EMUs: kg/seat by decade of introduction	493.4	519.5	559.6	719.7	704.5
DMUs: kg/seat by decade of introduction	none	533.0	608.8	796.9	612.7
Bi-Modes: kg/seat by decade of introduction	none	none	none	none	722.2

The first row of Table 4.5 shows a composite value based upon all three types of trains – EMUs, DMUs and Bi-Modes. Trains in the extended database that were introduced in the UK during the 1970s and 1980s had an average weight of 493.4 and 524.0 kg per seat. This increased by approximately 10% for trains introduced in the 1990s, and then increased significantly for trains introduced in the 2000s. The most recent trains show a reduction but not to the levels of the 1970-90s. The other rows show the values for EMUs, DMUs, and Bi-Modes, respectively.

The visual inspection of Figure 4.7 above, and the summary in Table 4.5, both provide support for an increase over time in the weight of rolling stock relative to the number of passenger seats. **Step two of the analysis, using a larger database of EMUs, DMUs and Bi-Modes, provides further support to the increase of rolling stock weight per passenger seat.**

The larger database created for step two of this analysis contains a diverse mix of trains. Some were designed to operate in rural areas, some provide long-distance inter-city services, and some operate constant commuter duties. To illustrate this diversity Figure 4.8 below shows a Class 144 *Pacer* DMU (top) and a Class 390 *Pendolino* EMU (bottom). The graphic also shows a visualisation to represent the cars making up the train, and how each car contributes to the train's total length, number of seats, and weight.

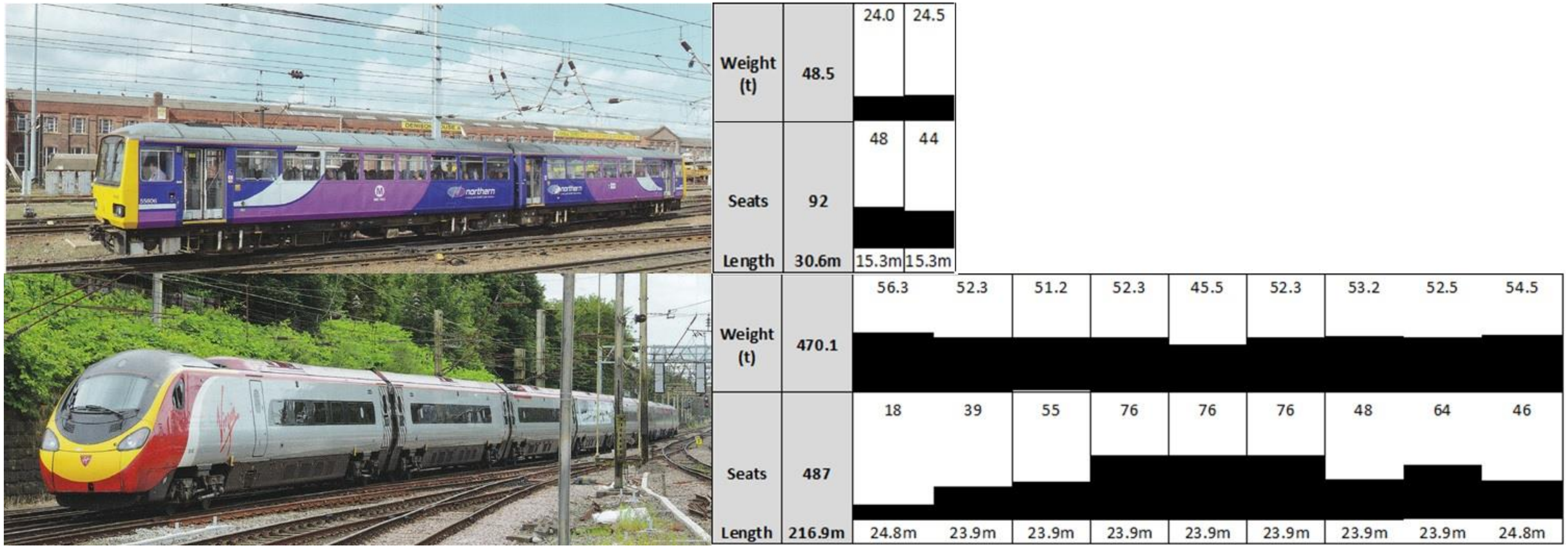


Figure 4.8 Class 144 Pacer DMU and Class 390/0 Pendolino EMU with visualisation of length, seats, and weight

Class 144 top and Class 390/0 bottom. Images source: (Marsden, 2014, pp. 95 and 225)

The Class 144 DMU (top) was first introduced in 1986. The trainset shown here operates as a 2-car formation, with diesel motors in both cars allowing it to reach a top speed of 121 km/h. This 2-car train has 92 seats available, with 48 in one car and 44 in the other – the second car has fewer seats because of the presence of a toilet. Once again this illustrates the different configuration of resources that can collectively act as a train with different attributes. Each carriage of the Class 144 is approximately 15m long and so the train is 30.6m long. The car with a toilet weighs 24.5 tonnes and the other 24 tonnes, giving a combined weight for this trainset of 48.5 tonnes. The relative weight per passenger seat is 527.2 kg/seat.

By contrast, the Class 390 *Pendolino* EMU was first introduced in 2001. There is an 11-car formation (390/1), but the one show here (Figure 4.8) is a 9-car formation (390/0) that has electric motors on seven of the nine cars. This allows it to reach a top speed of 225 km/h, drawing power for its motors from the AC overhead electric lines. The carriages are approximately 23m long and the 9-car Pendolino is 216.9m long, with 487 seats across standard and first, including a kitchen and onboard shop. The nine cars have seven toilets, including two with disabled access. The total weight of the trainset is 470.1 tonnes, with individual cars ranging from 45.5 tonnes, for a standard-class unpowered trailer (i.e., no motor) through to 56.3 tonnes for the first-class kitchen car that is motorised. The relative weight per passenger seat is 965.3 kg/seat.

These two different trains illustrate the diversity of the 157 different classes and sub-classes of trains that make up the extended database used for step two of this analysis. Comparisons between a Pendolino, introduced in 2001, and a Pacer, introduced in 1986, should be treated with caution. Therefore, to allow for analytical comparisons over time, step three focuses upon a common type of train within this larger database. This common type of train is the suburban Electrical Multiple Units providing a service to commuters in and around major cities. Step three of this investigation identifies the relevant trains that have performed this service over time, and then analyses changes in their weight per seat.

4.4 Step three: focus upon a common type of train

Step three focuses upon the same type of suburban EMU introduced between the 1970s and the present day – the same time horizon as Figure 1.5. For this analysis, trains were split into four tranches – two earlier tranches (1970s to 1990s) and two later tranches (1990s to 2019). I owe thanks to Roger Ford of *Modern Railways* for this suggestion to focus upon four tranches of commuter EMUs to help with comparability over time. The trains included within each tranche are based upon suggestions from Roger Ford, and my own analysis. To give further confidence in the comparability that this approach introduces we will see that trains introduced in later tranches often replace trains within an earlier tranche. For example, the Class 377, within tranche three, replaced Class 319s, in tranche one. This approach also gave a mechanism to separate trains introduced in different eras of the railway. Tranches one and two included trains introduced under British Rail, whereas the latter two included trains introduced after privatisation.

Tranche one trains include a variety of suburban EMUs introduced from the early 1970s under British Railways. Two classes are also included in tranche one, even though they discontinued service in 1980. The Class 445 and 446 EMUs are included within Tranche one because they were early BR prototypes that led to many subsequent designs included in this analysis. Tranche two trains include the *Networker* trains, which were introduced by BR in the 1990s to operate in the South East of England and around London. Tranche three trains include the trains introduced after privatisation and produced by Alstom, Siemens and Bombardier, and others. Tranche four trains include the most recent trains introduced after 2010, including the new trains for Thameslink and Crossrail, which are a focus for Chapter 6 of this analysis. The detailed list of classes and sub-classes allocated to each tranche is shown in the appendix in Table 9.12 (page 348).

The tranches in this analysis only contain Electric Multiple Unit (EMU) trains, so they all use electric motors, although some may draw power from overhead AC lines, some from third rail DC power, and some from both sources. All trains are designed to provide a similar type of commuting service – generally moving a lot of people in and out of large cities and towns. The trains within the tranches consist of cars that are 20-metres in length, which means that analysis of the number of seats and weight of trains is using a consistent length dimension. There is one exception to this. The recent Class 345 Crossrail trains are included in the fourth tranche, even though they are 22.5m long carriages. They are included because, like the other trains, they are an EMU and provide a commuting service into London. Also, the

Class 345s are replacing trains included in tranche one and tranche three, which provides assurance of their similar purpose.

Each of the tranches are described in the following sections, with a photograph of a train from that tranche.

4.4.1 Description of the trains across the tranches

The first tranche starts with BR prototype trains assigned as class number 445 (4-car) and 446 (2-car) that entered service in 1971. Their operational service ended in 1980 but these prototypes led to a range of subsequent EMU designs. A photograph of the Class 445 4-car from tranche one is shown below in Figure 4.9.

Figure 4.9 Interior and exterior photographs of the 4-car Class 445 – a tranche one train introduced in 1971.

Source:(Marsden, 1983, pp. 94–95)

Tranche two trains includes the *Networker* class of trains that operated in the South East of England. A Class 465, introduced in 1991, is shown in Figure 4.10 below.

Figure 4.10 Interior and exterior photographs of Class 465 4-car Networker – a tranche two train introduced in 1991

Source:(Marsden, 2014, p. 247)

Tranche three trains include the first trains introduced after privatisation. A photograph of Classes 377/4 built by Bombardier is shown in Figure 4.11 below.

Figure 4.11 Interior and exterior photographs of Class 377 4-car Electrostar – a tranche three train introduced in 2004

Sources:(train interiors: Marsden, 2007, p. 213, train exteriors: 2014, p. 215)

Finally, tranche four includes the most recent EMUs introduced since privatisation and after 2010. A picture of a Class 345 built by Bombardier for Crossrail is shown in Figure 4.12 below.

Figure 4.12 Interior and exterior photographs of Class 345 9-car Aventra – a tranche four train introduced in 2015

Source:(Pritchard, 2018b, p. 68); Class 345 interior: Sunil060902 - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=60737188;

4.4.2 Analysis across the four tranches

If we compare across the four tranches then we see (Table 4.6 below) that weight per seat has indeed increased over time, with tranches three and four heavier than their predecessors. Tranche four has decreased relative to tranche three, which will be explored further later.

Table 4.6 Summary of the characteristics of trains across the four tranches of analysis

	Number in tranche	Min number of cars	Max number of cars	Average weight of set (tonnes)	Average number of seats per set	Average weight per passenger seat (kg/seat)
Tranche 1	25	2	4	125.2	249.0	**502.8**
Tranche 2	6	2	4	127.5	300.0	**425.3**
Tranche 3	33	3	5	170.8	241.2	**708.0**
Tranche 4	4	5	12	288.0	458.5	**628.0**

Tranche one has 25 different classes and sub-classes, including the Class 445 shown in Figure 4.9 above. (Note: the specific classes in each tranche are listed in the appendix in Table 9.12). Tranche one trains range from 2-car configurations through to 4-car sets. The average weight of a tranche one trainset is 125.2 tonnes, with approximately 249 seats, giving an average weight per passenger seat of 502.8 kg/seat.

Tranche two has 6 different classes and sub-classes, including the Class 465/9 4-car shown in Figure 4.10 above. The tranche two trains range from 2-car formations through to 4-car sets. They weigh an average of 127.5 tonnes with approximately 300 seats per set, giving a figure of 425.3 kg/seat.

Tranche three has 33 different classes and sub-classes, including the 377/4 4-car *Electrostar* shown in Figure 4.11 above. The trains range from 3-car trainsets through to 5-car sets. The average weight of a tranche three set is 170.8 tonnes with approximately 241 seats per train, giving a figure of 708.0 kg/seat.

Tranche four trains are the most recent. There are four different classes and sub-classes of trains within this group, including the Crossrail Class 345 9-car *Aventra* shown in Figure 4.12 above. The trains in this group range from 5-car formations through to 12-car sets. The average weight of a tranche four trainset is 288.0 tonnes with approximately 459 seats, giving a figure of 628.0 kg/seat.

Trains from the four tranches are plotted in Figure 4.13 below. As with previous charts, the horizontal axis shows the year of first introduction, and the vertical axis shows the weight of the trainset per passenger seat.

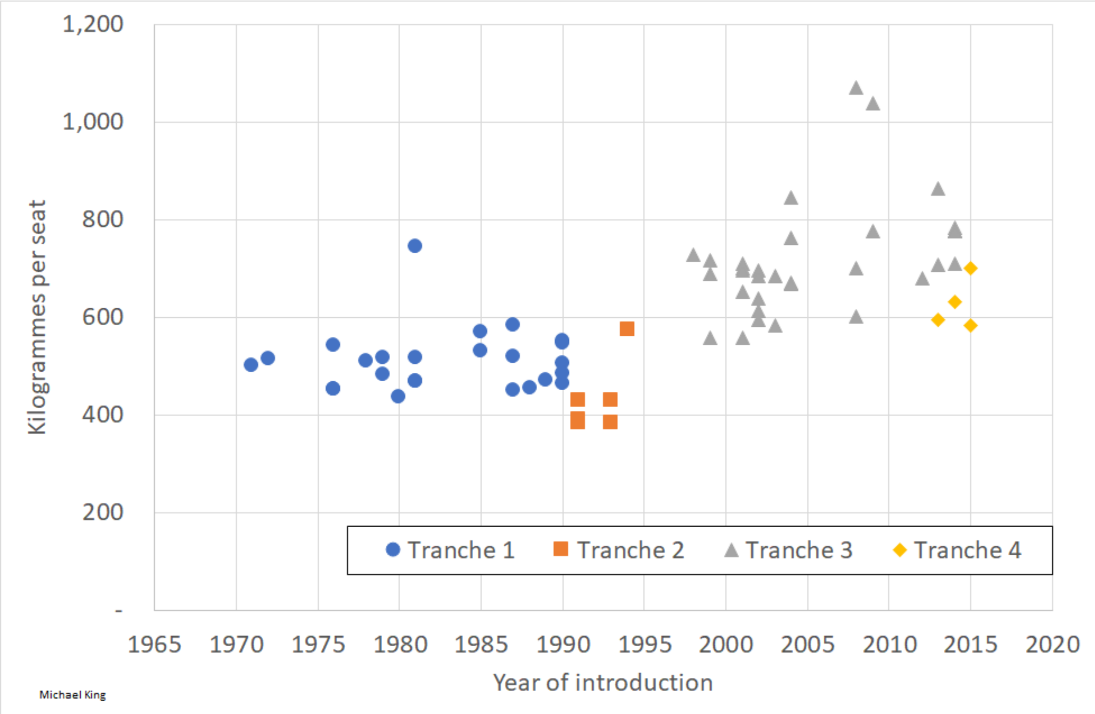


Figure 4.13 Historical vehicle mass per passenger seat across four tranches of the same type of train

Tranche one trains (blue circle) were introduced from the 1970s up to 1990 and show a spread around the average of 502.8 kg/seat (Table 4.6 above). The *Networker* trains of tranche two (orange square) were introduced in the 1990s and are clustered around the average of 425.3 kg/seat – the lowest average of the four tranches. Tranche three trains (grey triangle) were introduced from the 1990s through to 2015 and show a spread around the average of 708.0 kg/seat – the highest average of the four tranches. The fourth tranche (yellow rotated square) includes the most recent trains to enter service and they are clustered around the average of 628.0 kg/seat – a reduction on tranche 3, but not as low as tranches one or two.

Step three of this analysis gives further support to the increase in the weight per seat of rolling stock over time. Trains introduced since the late 1990s are heavier per seat compared to their predecessors. There is evidence that the most recent trains (tranche 4) have reduced relative to tranche 3, but they are still heavier per seat than trains in tranches one and two.

4.5 Step four: drill down to the factors of weight per seat

The metric used so far (kg/seat) has two parts: the total weight of that trainset and the number of seats on the trainset.

$$Weight\ per\ seat\ (kg\ per\ seat) = \frac{Total\ weight\ of\ the\ trainset\ (kg)}{Total\ number\ of\ seats\ available\ (seats)}$$

Weight per seat could increase because the train weight was increasing, or there were fewer seats, or some combination of both. Each component will now be explored.

4.5.1 The total weight of the trainset

The weight of a trainset will obviously be larger for 12-car trainsets than single car trains. Therefore, to help with comparison across trains this analysis will look at the average weight of a single car within the trainset. For example, a Pendolino train with nine cars weighs 470.1 tonnes, which implies an average weight of 52.2 tonnes per car. The following analysis looks first at the weight of an average car across the database of EMUs, DMUs and Bi-Modes created in step two, and then across the four tranches of suburban EMUs created in step three.

Figure 4.14 below shows the average weight of a single car across the 157 Classes and Sub-Classes (91 EMUs, 57 DMUs and nine Bi-Modes) of trains created in step two. The horizontal axis shows the year of introduction, as with previous charts, but the vertical axis now shows the average weight of a single car measured in tonnes.

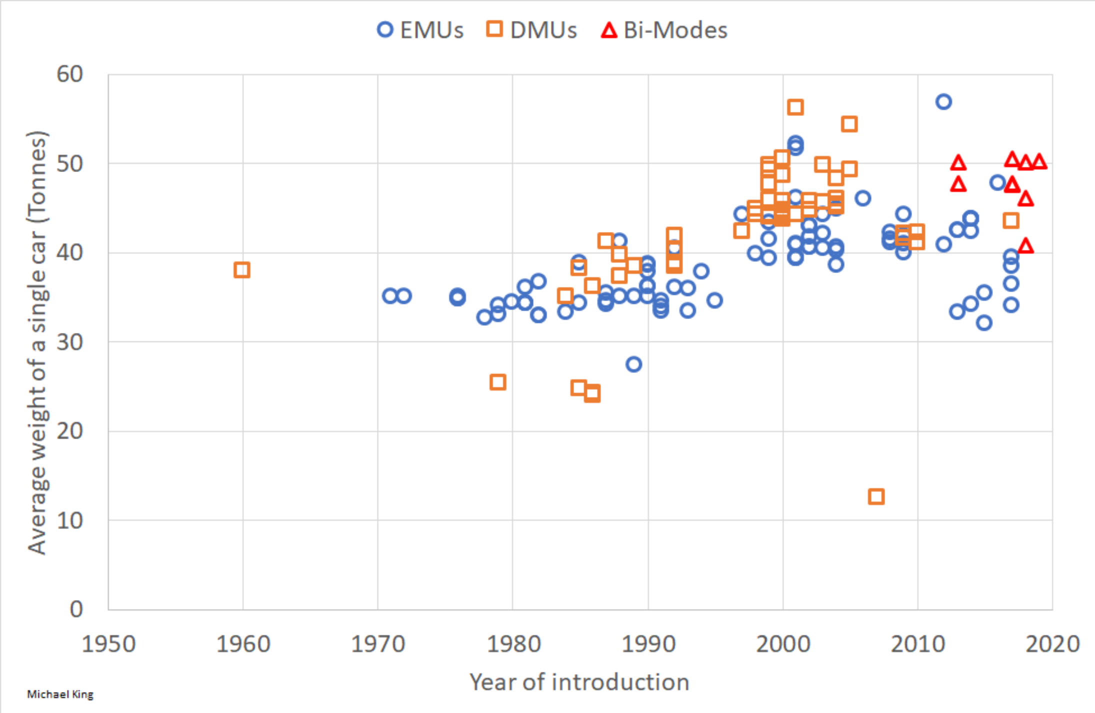


Figure 4.14 Historical vehicle mass (tonnes) for EMUs, DMUs and Bi-Modes

A visual inspection of Figure 4.14 shows an increase in weight for trains introduced during the late 1990s and 2000s relative to earlier trains. There is one DMU (orange square) which is a notable exception, introduced in 2007 and weighing significantly less than the others, but this will be discussed later in this section.

Recent EMUs (blue circles) introduced after 2010 show a spread of weights, with some appearing to be a similar weight to the earlier trains. The few recent DMUs (orange squares), introduced after 2010, appear to be heavier that the DMUs of the 1970-1980s. The Bi-Modes (red triangles) introduced recently are heavier than trains introduced before the early 1990s. To supplement this visual inspection, the changes over the decades are shown in Table 4.7 below.

Table 4.7 Average vehicle mass per car for EMUs, DMUs and Bi-Modes across the decades

Item	1970s	1980s	1990s	2000s	2010s
Composite of three train types: Weight per car (Tonnes) by decade of introduction	34.3	34.9	39.5	44.6	42.9
EMUs: Weight per car (Tonnes) by decade of introduction	34.3	35.0	37.6	43.3	40.0
DMUs: Weight per car (Tonnes) by decade of introduction	none	34.6	43.1	46.9	42.1
Bi-Modes: Weight per car (Tonnes) by decade of introduction	none	none	none	none	48.1

The first row shows the composite figure for all trains in the database. The composite data shows that an average train in this database of 157 classes increased in weight over time, until the most recent trains introduced after 2010. In the 1970s an average car in a train would weigh 34.3 tonnes. For trains introduced in the 2000s this had increased to 44.6 tonnes. Trains introduced after 2010 have reversed this increasing trend, but still weigh 42.9 tonnes on average, heavier than their earlier predecessors.

Of the 96 EMUs in this database, those introduced in the 2000s were the heaviest of all – with a single car weighing an average of 43.3 tonnes. For rolling stock introduced after 2010 this reduced to 40.0 tonnes per car, which is still heavier that those introduced between 1970 and 1990. A similar change is visible in the table for DMUs, with the heaviest vehicles introduced in the 2000s, compared to the lightest trains introduced during the 1980s. Bi-Modes are new to British railways and so there is no historical comparison to make, but it is interesting to note that they have the heaviest cars on average for vehicles introduced after 2010. A Bi-Mode car, introduced after 2010, weighs an average of 48.1 tonnes compared to 40.0 tonnes and 42.1 tonnes for EMUs and DMUs, respectively. This could be explained by their configuration of resources that includes diesel **and** electric motors – in this case the beneficial attribute of greater flexibility to travel across the network is associated with increased weight.

It was noted above that there is one significant outlier in Figure 4.14 – a DMU (orange square on the chart) with a much lower weight than the others. This is a Class 139, first introduced in 2007, and it is a single car train, weighing 12.5 tonnes. A picture of the Class 139 is shown below in Figure 4.15. There are only two Class 139s in service, but this is another example of the diversity of resources that can be configured to act as trains. The Class 139s began as a trial for a lightweight railcar for quiet branch lines. They have an onboard engine combined with a flywheel that reduces the need for a larger engine.

Figure 4.15 Class 139 DMU - the lightest weight car of the dataset

Source:(Marsden, 2014, p. 88)

Step three in the earlier analysis addressed this diversity in train types by focusing upon suburban EMUs. Figure 4.16 below shows the analysis of train weight across the four tranches.

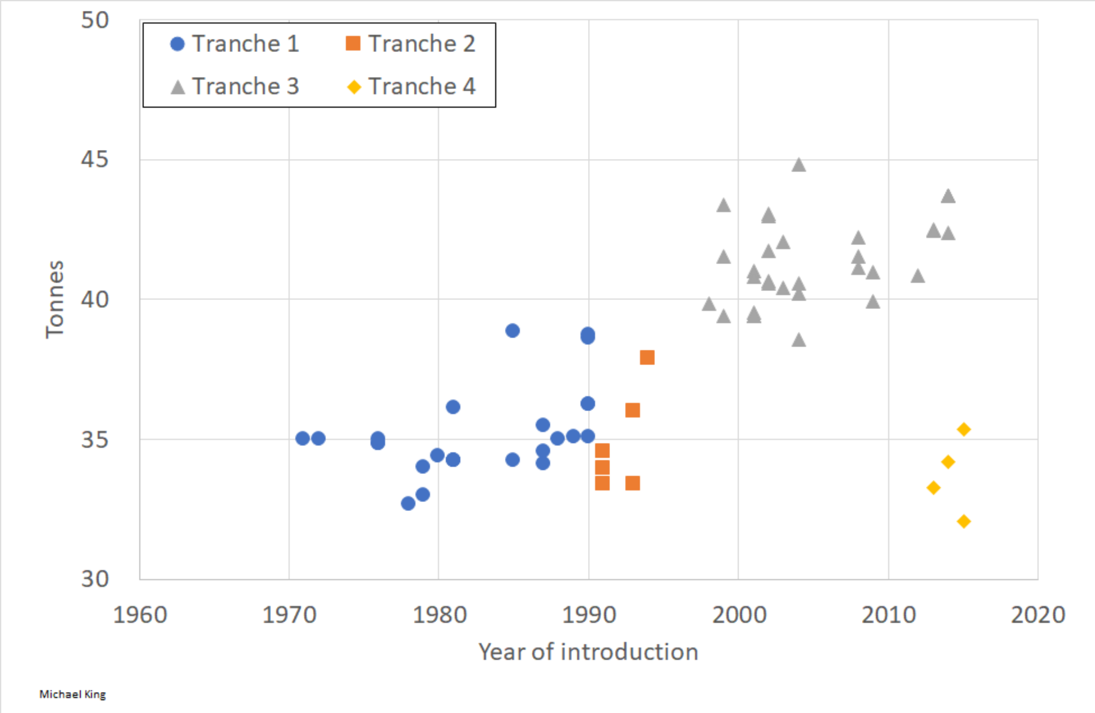


Figure 4.16 Historical vehicle mass (tonnes) across the four tranches of suburban EMUs

A visual inspection of this chart shows a definite increase in the weight of tranche three trains (grey triangle) compared to earlier tranches one (blue circle) and two (orange square). However, tranche four trains (yellow rotated square) show a reduction in vehicle weight down to the level of earlier trains.

The average weight of a car in tranche one is 35.2 tonnes and 34.8 tonnes for tranche two. This compares to an average tranche three car weighing 41.4 tonnes and tranche four at 33.9 tonnes. This confirms the visual inspection that tranche four trains are the lightest on average, and tranche three trains the heaviest. The tranche four trains include the recent procurements for Thameslink and Crossrail that are explored in detailed in Chapter 6. The key point that can be made here is that this analysis provides evidence that weight increase was not, and is not, inevitable.

The next section completes the analysis in step four and looks at the other component of kg per seat: the number of seats available.

4.5.2 The number of passenger seats

The chart below (Figure 4.17) shows the average number of seats for a single car across the database of 157 classes and sub-classes (96 EMUs, 57 DMUs and nine Bi-Modes).

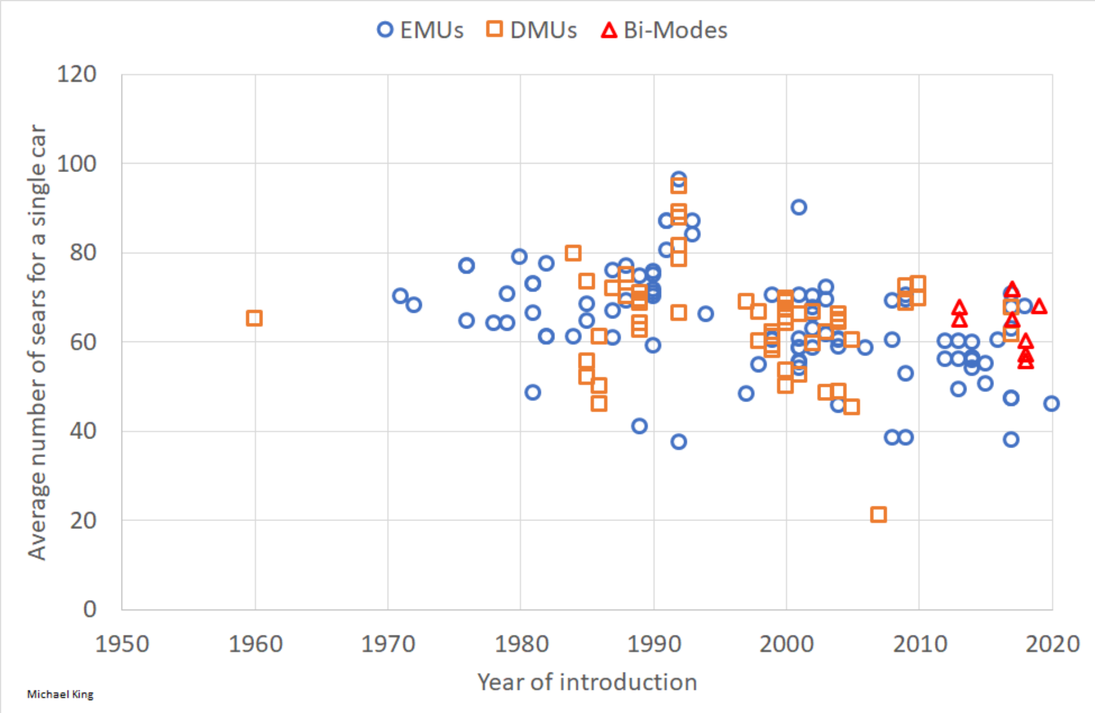


Figure 4.17 Historical number of seats per car for EMUs, DMUs and Bi-Modes

A visual inspection of Figure 4.17 shows an apparent general trend downwards, with fewer seats available over time. This visual inspection can be confirmed by analysis grouping trains into the decade of their introduction, as shown in Table 4.8 below.

Table 4.8 Average number of seats per car for EMUs, DMUs and Bi-Modes across the decades

Item	1970s	1980s	1990s	2000s	2010s
Composite of three train types: Seats per car by decade of introduction	69.5	66.5	68.5	59.7	60.7
EMUs: Seats per car by decade of introduction	69.5	67.3	67.3	60.2	56.8
DMUs: Seats per car by decade of introduction	none	64.9	70.9	58.8	68.7
Bi-Modes: Seats per car by decade of introduction	none	none	none	none	66.6

The first row shows the composite figure for all trains in the database. The composite data shows that an average train in this database had fewer passenger seats after the 2000s compared to earlier decades. In the 1970s a single car in a train would have 70 seats on average. For the most recent trains, introduced after 2010, this had reduced to 61 seats.

The EMUs (second row) show a consistent reduction from approximately 70 seats per car in the 1970s through to 57 seats for trains introduced after 2010. The DMUs are more varied. An average DMU car introduced in the 2000s had only 59 seats, but this had risen to 69 seats in the 2010s. The small number of Bi-Modes, introduced after 2010, have 67 seats per car on average.

Finally, analysis of the four tranches of suburban EMUs is shown in Figure 4.18 below.

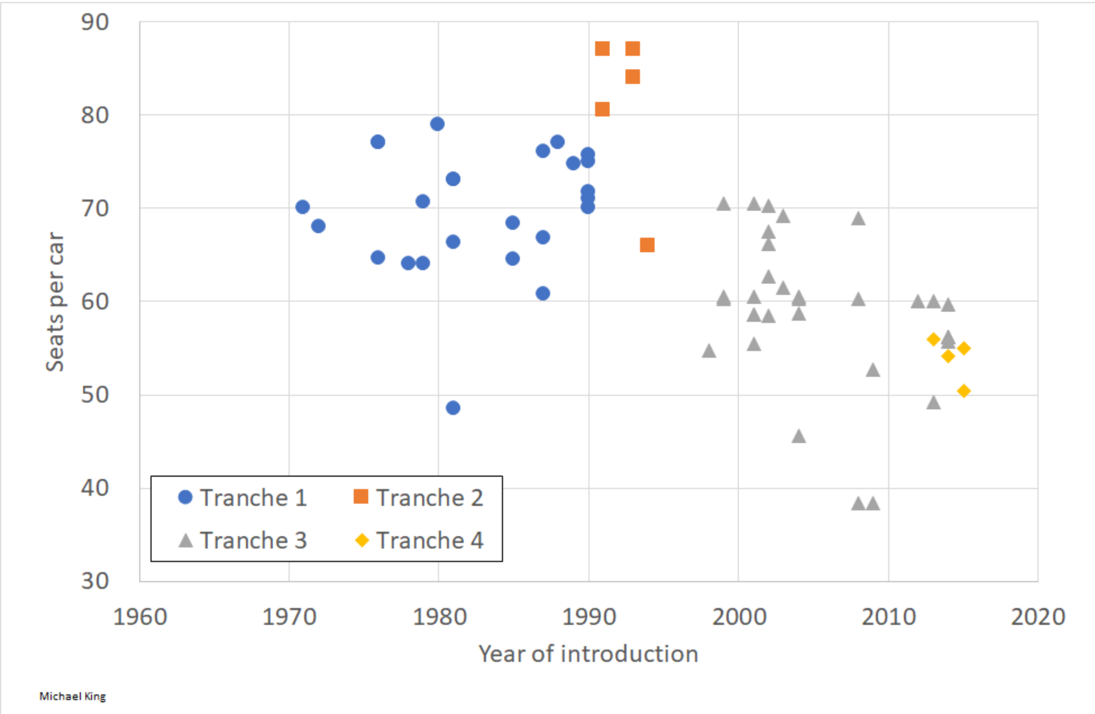


Figure 4.18 Historical number of seats per car across the four tranches

A visual inspection of this chart shows a marked reduction in seats available for trains in tranches three and four. Analysis of this dataset shows that a car in a tranche one trainset (blue circle) had 69 seats on average, whereas tranche two trains (orange square) had 81 seats per car. By tranche three (grey triangle), this had reduced to an average of 58 seats per car, and 54 seats for a car within a tranche four trainset (yellow rotated square).

To help visualise this, Figure 4.19 below shows an example interior for a train within each tranche.

Figure 4.19 Interior pictures for an example train from each of the four tranches

Tranche 1: Class 319 (top left); tranche 2: Class 465 Networker (top right); tranche 3: Class 377 Electrostar (bottom left); tranche 4: Class 700 Desiro City (bottom right)

Sources: Class 319 seating (Marsden, 2014, p. 171); Class 465 Networker seating (Marsden, 2007, p. 241); Class 377 Electrostar seating (Marsden, 2014, p. 215); Class 700 Desiro City by RM - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=58951382

The class 319 (top left) is within the tranche one group of trains. It was introduced in 1987 under British Rail and runs as a 4-car formation. The number of seats varies across sub-classes, but a Class 319/4 has 269 seats across the set and so an average of 67 seats per car.

The Class 465 *Networker* (top right) within tranche two was first introduced in 1991 under British Rail. There are some variations within the sub-classes, but a Class 465/9 runs as a 4-car formation with 322 seats across the set, giving an average of 80 seats per car.

The Class 377 *Electrostar* (bottom left) is within tranche three and replaced Class 319s in tranche one when it entered service. It was first introduced in 2001 and built by Bombardier under the privatised railway structure. The sub-classes of the 377 operate in three, four, and five-car formations, but a class 377/6 runs as a five-car formation with 300 seats across the set, giving an average of 60 seats per car.

The Class 700 *Desiro City* (bottom right) is within tranche four and replaced Class 319s in tranche one, and Class 377s in tranche three. It was first introduced in 2013 and built by Siemens under the privatised railway structure. The sub-classes run as eight and 12-car formations, but a Class 700/0 runs as an 8-car formation with 433 seats across the set, giving an average of 54 seats per car.

This analysis found **a reduction in number of seats for modern trains compared to their predecessors**. This is the case for the larger database created in step two and the four tranches of suburban EMUs created in step three. **Modern trains have a configuration of resources with fewer seats than their predecessors.**

4.5.3 Summary of the analysis in step four

Steps one, two and three used the metric of weight per seat (kg/seat) over time and found supporting evidence for trains getting heavier over time relative to the number of seats. Step four of this analysis has investigated the two components that make up this metric: the train's total weight and the number of passenger seats available. **The increase in the weight per seat over time can be accounted for by increases in the weight of the rolling stock and reductions in the provision of seating.** Table 4.9 below gives a summary of this analysis using the extended database created in step two.

Table 4.9 Summary of the train weight and number of seats across the extended database

Item	1970s	1980s	1990s	2000s	2010s
Weight per car (Tonnes) by decade of introduction	34.3	34.9	39.5	44.6	42.9
Seats per car by decade of introduction	69.5	66.5	68.5	59.7	60.7
Weight per seat (kg / seat) by decade of introduction	493.4	524.0	577.1	747.8	706.5

Trains introduced during the 1970s and 1980s weighed on average 34.3 – 34.9 tonnes per car and had approximately 70 and 67 seats per car, giving a weight per seat of 493.4 and 524.0 kg per seat, respectively. For trains introduced during the 2000s and 2010s the weight per seat had increased to 747.8 and 706.5 kg per seat, driven by heavier trains and a reduction in the number of seats.

A summary across the four tranches of suburban EMU is shown in Table 4.10 below.

Table 4.10 Summary of the characteristics of trains across the four tranches

Item	Kg/seat	Weight per car (Tonnes)	Number of seats per car
Tranche 1	502.8	35.2	69.9
Tranche 2	425.3	34.8	81.7
Tranche 3	708.0	41.4	58.5
Tranche 4	628.0	33.9	53.9

Tranche three trains, built immediately after privatisation, are heavier and have fewer seats than their predecessors. However, the most recent tranche four trains, including those built for Thameslink and Crossrail, weigh 33.9 tonnes per car and are lighter than any of their predecessors in this analysis – a demonstration that weight increase was not inevitable. However, a car in a tranche four train has only 53.9 seats on average, compared to tranche two trains that had some 81.7 seats.

Step four of this analysis confirms that the increase in the weight per passenger seat of British trains is attributable to both the increased weight of the trains, and a reduction in the number of seats available for passengers. The tranche three trains introduced immediately after privatisation are the heaviest, although the most recent tranche four trains have achieved the lightest weight of all. The number of seats has reduced significantly for the trains in tranches three and four compared to their older peers, and this is the reason why both tranches three and four have a heavier figure for kg per seat compared to tranches one and two.

4.6 Summary of all four analytical steps

Step one of the analysis reproduced the increase in weight per seat of the group of trains shown in the original chart (Figure 1.5) that prompted this research. The second step expanded the analysis to a database of 157 different types of EMU, DMU and Bi-Mode trains. This larger database also showed an increase in the weight per seat of trains over time. Trains introduced during the 2000s were the heaviest, whereas those introduced after 2010 were a bit lighter, but this did not reduce to the levels of trains introduced during the 1970s – 1990s. Step three focused upon suburban EMUs split into four tranches. The analysis in step three also found that weight per seat increased over time. The tranche two trains, introduced during the early 1990s, were the lightest per seat; the tranche three trains, introduced from the late 1990s through to 2010, were the heaviest per seat, but the most recent tranche four trains showed a reduction in weight per seat relative to trains in the earlier third tranche.

The fourth and final step found that the number of seats available on trains has reduced significantly over time. Trains introduced after 2000 have nearly 10 fewer seats per car than trains introduced earlier. With several cars forming a trainset this could make a significant difference to the total number of seats available for passengers. The weight of trains was not quite so clear a story. For the extended dataset of EMUs, DMUs and Bi-Modes, the trains introduced during the 2000s weighed nearly 10 tonnes more per car than their predecessors. However, analysis of suburban EMUs found that the most recent trains, introduced after 2010, were the lightest of all four tranches.

A chart showing an outcome of heavy trains was the starting point for this research. It was essential to know if this starting point provided a good foundation for subsequent work. This analytical chapter has built an empirical base to enrich (White, 2010) the analysis in the following chapters. There is good evidence for an increase in train weight and a reduction in the availability of seats. Recent trains have attributes with fewer seats and more weight compared to their predecessors from the 1970s and 1980s.

The actions that produced these trains can all be understood as strategic decisions followed by a manufacturing stage. Propositions of trains were created, one of which subsequently became a realised train. In the nationalised operations of British Rail this might not have been a competitive procurement process, but there might have existed different conceptions of the trains. The current railway industry has a mix of private and public sector organisations involved in these strategic decisions, but the characterisation remains the same: propositions exist before a translated realised train enters service. The production of new trains is a significant endeavour, whether that involves just two Class 445 trains (Figure 4.9), which were built by British Rail as prototypes in the 1970s, or the £1.6Bn Thameslink contract awarded to Siemens in the 2010s.

Tranche 3 trains are visibly heavier than their predecessors introduced by British Rail. However, we should be way of simply ascribing the blame for heavy trains to ‘privatisation’ or ‘competitive sourcing’, because the most recent tranche 4 trains are the lightest of all. The phenomenon of heavy trains will be investigated further by applying ANT theory to understand the strategic decisions that produce trains. Different configurations of resources can be brought together to act as a train; some will have attributes of excess weight. The following chapters build upon the empirical analysis of train weight to understand how new trains are produced – historically and in recent times.

5 Historical Analysis of the Railways using ANT

We know from the empirical analysis in Chapter 4, that trains have generally increased in weight per seat, and this is attributable to an increase in the weight of the trains, as well as a reduction in the number of seats available for passengers. This is a problem because heavy trains use more energy and produce more emissions, potentially over an exceptionally long period. This is the first of two chapters to investigate how the general increase in the weight of trains has happened.

This historical analysis does not aim to produce a definitive history of the railways, rather it develops a broad view on how the railways and trains have developed over time. This is not some passive context (Latour, 1996, p. 133), before getting onto the real action in the next chapter, which investigates two recent strategic decisions that have actually produced lightweight trains. **The goal of the historical analysis is to use ANT analysis to demonstrate that trains and railways are dynamic and fluid concepts, even when made of iron and steel.**

This chapter will apply ANT as the theoretical lens to understand the actors and actions taking place as the industry changes. This action includes famous names, such as Brunel, that are in the spotlight of performance, but ANT's distributed view of agency recognises a wider group of actors making up the network. The model of five circulating loops (Latour, 1999, p. 100), described in Chapter 2 and shown in Figure 2.2 (reproduced again below in Figure 5.1) will be the main tool to understand the actor-networks that act as, and act upon, the railway. Thinking with the loops enables us to see the human and non-human actors that come together to act upon and shape how the railway is performed over time.

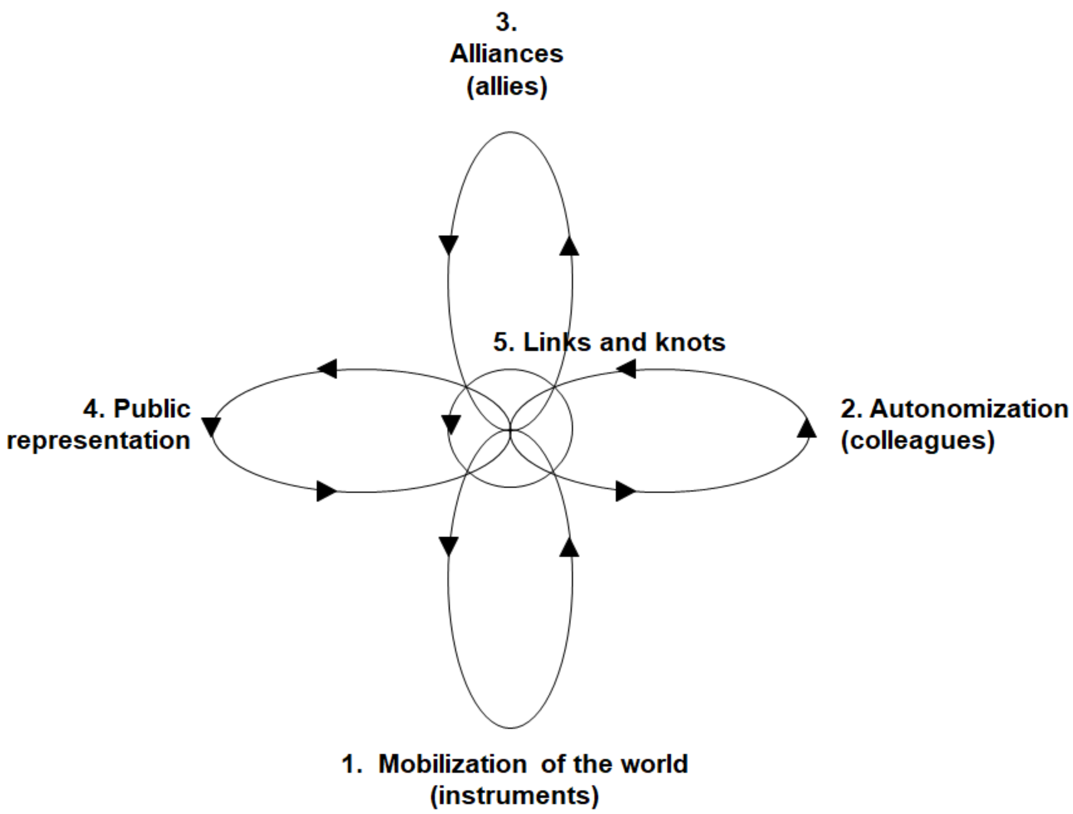


Figure 5.1 Theoretical model of five circulating loops used in this ANT analysis

Source: (Latour, 1999, p. 100)

The analysis in this chapter is framed around four stages in the development of British railways. The first stage covers the earliest railways, that appear at the end of the 18th century, followed by the subsequent development of locomotive engines in the early 19th century. This first stage is a period of rapid growth, driven by hundreds of companies building and operating new railways across the country. The second stage sees industry consolidation after World War One, with the multiplicity of railway organisations combined to produce the era of the *Big Four* railways. This second period ran, approximately, from World War One until the end of World War Two, when the third stage begins with nationalisation and the creation of British Rail (BR). The nationalised railway was in place until the 1990s, when the fourth and current stage began, with the era of privatisation. None of these stages are perfectly delineated, however, they provide a structure for the analysis that follows.

To help understand the changing nature of the railways I used four descriptive statistics that measure different aspects of the railway over time. As explained earlier in Section 3.4, these statistics provide a consistent way to understand the railway as it changes over time. The statistics used are: the length of railway track; industry receipts for passengers and goods; the number of passenger journeys; and railway income, expenses, and profitability. The following sections contain charts, produced from my own analysis of these variables, to help create a richer picture of the changes taking place across the four stages. For example, the phenomenal growth of the early 19th century is visible in a classic ‘S-curve’ shape for the length of track built during this time, but this curve flattens as the railway matures and enters the era of the Big Four, in the second stage.

5.1 A multiplicity of local railways and the development of a national rail network

The early railway is characterised by “impermanent affairs” (Holland, 2015, p. 16) involving a lot of experimentation and exploration. The railway in the late 18th and early 19th century is a transitory and temporary service, driven by specific local needs, which mostly involve the movement of goods such as coal, from mines to ports and cities. The early focus upon the movement of goods brings merchants and traders into the network of relationships (loop 3, alliances) that act as railways. Landowners are often part of this network if, for example, they own the mine or require payment in return for granting the railway temporary access across their land. At this stage in its development, the railway cannot act without these actors in the network.

A specialist railway profession (loop 2, autonomization) begins to emerge from the experimentation taking place, with experts produced from the amateurs learning how to solve the many problems that railways encounter. The sight, noise and smell of the machines begins to build a relationship with the wider public (loop 4, public representation), even if they are not involved as passengers initially.

The early temporary nature of the railway changed when Acts of Parliament permitted companies to purchase land outright. The Acts allowed the substitution of landlords in the actor-network of a railway. In 1758 “the Middleton Railway of Leeds became the first railway in Britain to be granted powers of permanence by an Act of Parliament” (Holland, 2015, p. 16) to carry coal from local pits to a nearby river for onward transport to the city of Leeds. The actor-network of this early railway used horses for traction. Initially it ran upon wooden rails, before these were replaced later with iron, with this material change acting to allow heavier loads to be hauled.

Individuals begin to emerge as recognised experts. The developing profession of the railways (loop 2, autonomization) begins to grow and incorporates the local knowledge that is gained as local problems are met and overcome. Some of these early lessons will go on to become widely adopted as standard practice in the production of railways. For example, *track gauge* measures the distance between the rails and, in the current UK mainline railway this is 4 feet 8 ½ inches, which is now known as *standard gauge*. However, before standard gauge was accepted into practice, the early railways needed to create their own gauge, as was the case with the Middleton Railway, which used 4 feet and 1 inch. The Middleton still acted as a railway, despite its non-standard gauge and the configuration of resources that included wheels with this gap.

The ability to purchase land reduced the temporary nature of railways. Increasing permanence of the railway was also demonstrated when the Surrey Iron Railway became the world's first *railway company*, in 1803. It was "established by an 1801 Act of Parliament" (Holland, 2015, p. 17) and operated a 9-mile horse-drawn railway in South London. The Surrey Iron Railway was built instead of a planned canal, and it charged tolls of private users for its freight service to move coal, agricultural products, and other goods. A railway actor-network now included legislation that allowed the railway company to act in commercial and operational ways. This example also illustrates how railways were bringing canals and their owners (loop 3, alliances) into their networks, even if they are potential disruptors and blockers given the competitive threat that rail posed.

Passengers (loop 4, public representation) were first brought into the actor-network when the Oystermouth Railway became the world's first passenger-carrying railway (Holland, 2015, p. 17) after Parliamentary approval in 1807. This 5 ½ mile railway, around Swansea Bay in Wales, used "stagecoach-style vehicles" (Holland, 2015, p. 17) pulled by horses. The vehicles ran on *plateway* track, which was an L-shaped rail to guide the wheels of the coach. As rail began to specialise, this technology would be replaced by a smooth rail profile, with the use of flanged wheels to guide the train vehicles along the track. These improvements acted to allow for improvements in the speed, strength, and quality of the ride.

Early railways had many obvious differences to modern concepts of railways, with their wooden and plateway tracks of varying gauges, their power provided by horses, gravity, if on a slope, or even people pushing or pulling carts. However, these different socio-material networks of resources – human and non-human – all still collectively act, or perform, as a railway. Different actor-networks, that act as railways, will have different attributes, associated with their different socio-material configurations. Different attributes provide different railways with advantages, for example, the increasing use of iron rails allows for heavier loads to be carried, which could act to increase commercial revenue. The iron rails (a material entity) are in a relationship with the economic (a social entity). We could say that the economic acted, or caused, the introduction of iron rails, but ANT would discourage any privileging of the social to explain this actor-network configuration. They act together, collectively.

At the start of the 19th century the railways in Britain had grown in number, but were still "limited to small-scale, localised railroads operated by horses or by stationary engines" (Mitchell, 1988, p. 531). Engines were a noticeable absence from these early railway actor-networks, but this began to change. Engines were already used in factories, coal mines and elsewhere, and this expertise was brought into the railway profession (loop 2, autonomization). Stationary engines would involve a fixed engine hauling carts with pulleys and ropes. In 1817, an early steam locomotive was used on the Kilmarnock & Troon Railway in Scotland. The locomotive was used because it could haul ten tons of coal at 5mph, but it was soon replaced by horses because the locomotive's *5-ton weight* (Holland, 2015, p. 18) was too heavy for the brittle plateway track on which it operated. In this case the actor-network using horses and plateway track was the most articulate proposition of a train compared to an alternative actor-network using the locomotive with the plateway track. The locomotive had a weight attribute of 5-tons, which was an excessive weight when it was in a relationship with the brittle track. However, locomotives had made their appearance in the production of railways.

In 1825, in a significant historical development, the Stockton & Darlington Railway was built under the guidance of chief engineer, George Stephenson. This railway connected collieries in Darlington with docks on the River Tees at Stockton to transport coal from the mines to the port – once again we seen alliances (loop 3) formed in the actor-network of a railway. However, the railway initially faced opposition from local landowners (loop 3, alliances) who restricted access to their land. Alternative routes were developed, and the subsequent 1823 Act of Parliament that approved the railway was evidence of successful alliance building locally, and with Government (loop 3, alliances). This Act included the power to “use locomotive or moveable engines” (His Majesty’s Government, 1823, p. 665). At the launch of the railway on 27 September 1825, with enormous crowds and fanfare, George Stephenson’s steam-powered *Locomotion* hauled approximately 500 passengers (loop 4, public representation) in a coach and some converted coal wagons. For the first time in the world a “passenger-carrying steam train” (Holland, 2015, p. 30) had transported passengers on a public railway. An oil painting by Terence Cuneo (Figure 5.2 below), produced in 1949, captures the excitement of the time, with *Locomotion*, driven by George Stephenson, hauling a train of wagons carrying passengers, as crowds cheer alongside.

Figure 5.2 The Opening of the Stockton & Darlington Railway by Terence Cuneo

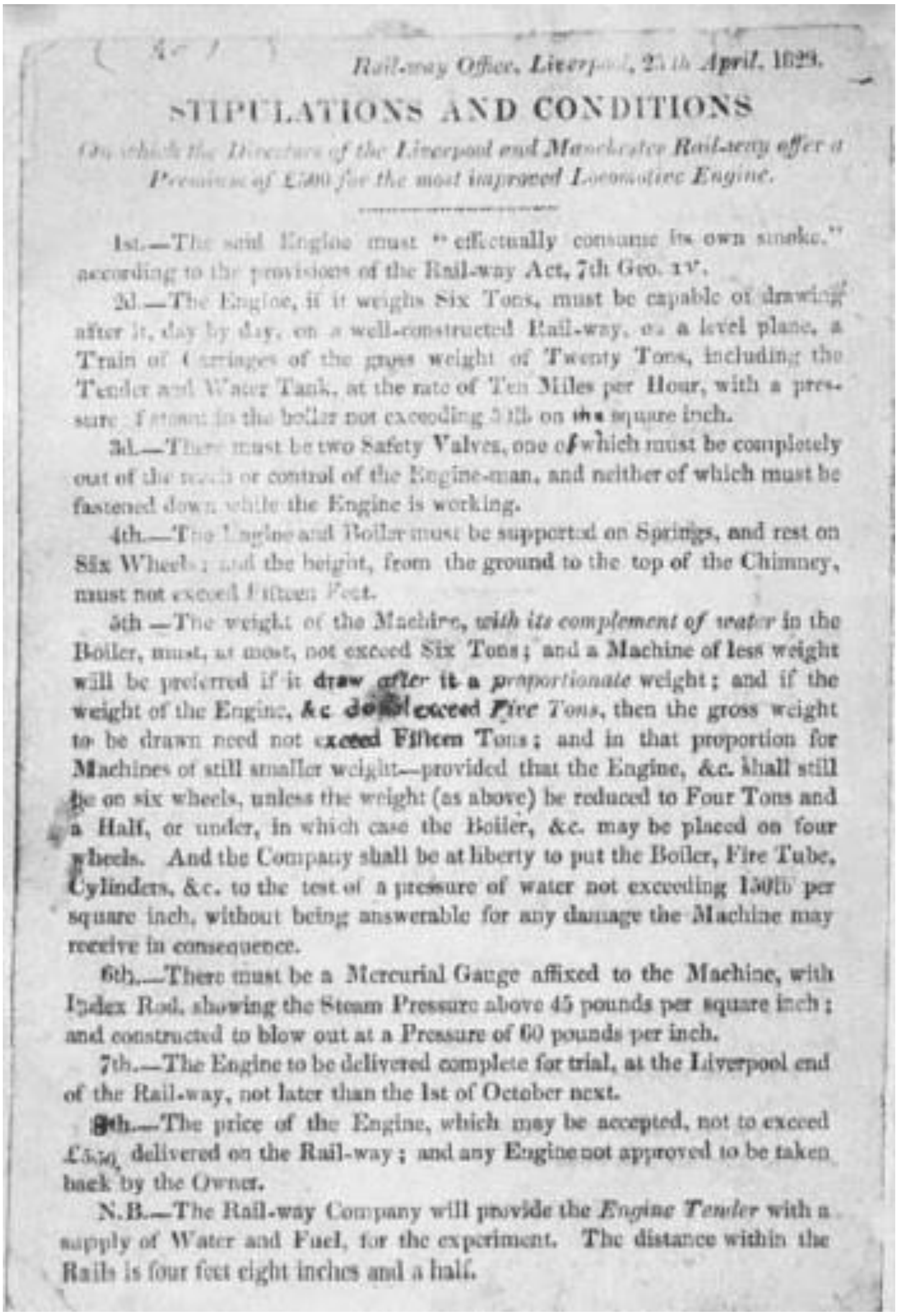
Source: (Holland, 2015, p. 31)

Stephenson designed the track gauge (the width between the rails) for the Stockton & Darlington Railway as 4 feet 8 ½ inches (1,435mm). This was based on his earlier colliery railways (Holland, 2015, p. 28), with an extra half inch added to reduce friction on curves, as the railway profession continued to learn how to produce railways (loop 2, autonomization). This width would go on to be adopted as *standard gauge* for railways around the world and remains in use in the current UK mainline railway. The engineer of the Great Western Railway, Isambard Kingdom Brunel, would hold out against this, with his trains using a Broad Gauge of 2,134mm, until 1892 when all services were converted to standard gauge. Trains using broad gauge still acted as trains, with some claiming advantages from this configuration, however their disadvantages were obvious when people were required to change trains because of a lack of interoperability.

Standard gauge was implemented in 1830 when the world’s first inter-city railway, the Liverpool & Manchester Railway (L&MR), opened for service. These two lines (S&DR and L&MR) marked the beginning of the “steam railway era” (Mitchell, 1988, p. 531). They both had “specialised track, mechanical traction, facilities for public traffic, and provision for passengers” (Gourvish, 1980, p. 9), which had been absent, or only partially present, in earlier railway developments. This actor-network of resources that acted as the railway would be recognisable today.

The Liverpool & Manchester Railway was built to provide cheap transport between the port of Liverpool and the textile mills of Lancashire. Merchants and traders are, again, an important part of the network (loop 3, alliances) producing this railway and making it act. Construction of the railway was a feat of significant engineering: the first railway tunnel under a city, and the crossing of Chat Moss, among many achievements. However, it is the Trials at Rainhill in October 1829, which are most well-known.

Locomotive power was still new when the railway was being built between the cities of Liverpool and Manchester. The Directors of the L&MR launched the Rainhill Trials in 1829, with a prize of £500 (more than £50,000 in 2019) for the winning locomotive and its owner. Competing participants in this strategic decision to identify the best locomotive were required to comply with given *stipulations and conditions* that are discussed in the introduction (Chapter 1) and shown in Figure 5.3 below.



Rail-way Office, Liverpool, 25th April, 1829.

STIPULATIONS AND CONDITIONS

On which the Directors of the Liverpool and Manchester Rail-way offer a Premium of £500 for the most improved Locomotive Engine.

1st.—The said Engine must "effectually consume its own smoke," according to the provisions of the Rail-way Act, 7th Geo. IV.

2d.—The Engine, if it weighs Six Tons, must be capable of drawing after it, day by day, on a well-constructed Rail-way, on a level plane, a Train of Carriages of the gross weight of Twenty Tons, including the Tender and Water Tank, at the rate of Ten Miles per Hour, with a pressure of steam in the boiler not exceeding 50lb. on the square inch.

3d.—There must be two Safety Valves, one of which must be completely out of the reach or control of the Engine-man, and neither of which must be fastened down while the Engine is working.

4th.—The Engine and Boiler must be supported on Springs, and rest on Six Wheels; and the height, from the ground to the top of the Chimney, must not exceed Fifteen Feet.

5th.—The weight of the Machine, *with its complement of water* in the Boiler, must, at most, not exceed Six Tons; and a Machine of less weight will be preferred if it draw after it a *proportionate* weight; and if the weight of the Engine, &c. do not exceed *Five Tons*, then the gross weight to be drawn need not exceed Fifteen Tons; and in that proportion for Machines of still smaller weight—provided that the Engine, &c. shall still be on six wheels, unless the weight (as above) be reduced to Four Tons and a Half, or under, in which case the Boiler, &c. may be placed on four wheels. And the Company shall be at liberty to put the Boiler, Fire Tube, Cylinders, &c. to the test of a pressure of water not exceeding 150lb. per square inch, without being answerable for any damage the Machine may receive in consequence.

6th.—There must be a Mercurial Gauge affixed to the Machine, with Index Rod, showing the Steam Pressure above 45 pounds per square inch; and constructed to blow out at a Pressure of 60 pounds per inch.

7th.—The Engine to be delivered complete for trial, at the Liverpool end of the Rail-way, not later than the 1st of October next.

8th.—The price of the Engine, which may be accepted, not to exceed £550, delivered on the Rail-way; and any Engine not approved to be taken back by the Owner.

N.B.—The Rail-way Company will provide the *Engine Tender* with a supply of Water and Fuel, for the experiment. The distance within the Rails is four feet eight inches and a half.

Figure 5.3 Stipulations and Conditions for the Rainhill Trials

Source: (image taken from Marshall, 1930, p. 1067)

The L&MR railway was not yet complete, but it was *brought into, or mobilised,* (loop 1, mobilisation of the world) in this strategic decision through the creation of a test track that represented the future railway between the two cities. The *stipulations and conditions* defined how competing locomotives would be measured (loop 1, mobilisation of the world) within the Trials. The stipulations and conditions included weight limits (less than six tons preferred), which represented the early fragility of track relative to the weight of locomotives. Other aspects of the future service were mobilised and brought into the strategic decision to identify the best locomotive. This included the ability of the locomotive to haul a train of carriages weighing 20 tons, with this weight representing future loads of goods and passengers. The requirements also specified a track gauge of 4 feet 8 ½ inches (standard gauge), safety characteristics, the price of the locomotive, and more. The competition was won by Robert Stephenson, son of George Stephenson, and his locomotive *Rocket*. He was awarded the contract to build and operate locomotives for the new railway.

The Liverpool & Manchester Railway opened on 15 September 1830, with a high-profile launch involving the Duke of Wellington, who was then the Prime Minister, and various politicians, merchants, and other local representatives demonstrating how the wider loops of the railway actor-network reached out and strengthened it (loop 3, alliances; and loop 4, public representation). The first train on the railway carried the Duke and others was hauled by the locomotive, *Northumbrian*, which Robert Stephenson had built after the Trials. Applying the theory developed in Chapter 2, *Northumbrian* is a realised train[5] that has been translated from the earlier winning proposition of a train, that was *Rocket* during the Trials. The translations that produced *Northumbrian* included improvements upon *Rocket's* design.

Rocket itself was also carrying passengers on the day of the launch. It is not possible to determine here whether the *Rocket* involved in the trials was modified in any way for operation on the L&MR, although that would seem likely given the pace of technological innovation and learning at the time. If changes were made, then there are effectively two *Rockets*: one that was a winning proposition of a train built for the experiments in Rainhill, running on the test track and hauling two carriages loaded with stones; and another *Rocket* that was a realised train transporting people and goods between Liverpool and Manchester.

The railway was an instant success, and the locomotive was established within the actor-network that acted as a train and railway. This successful configuration was about to be translated around the country and world.

[5] It might not be technically accurate to describe a locomotive without a rake of carriages as a train, but this is used for simplicity and to avoid talking about *realised locomotives* and *realised trains*. A *realised entity* could be used but this loses the industry language.

After this, the railways moved into a new stage of extreme growth, with a series of "promotion manias" (Gourvish, 1980, p. 9) between 1830 and the mid-1860s that raised money acted to support new railway companies across the country. Railway mania produced a **multiplicity of local railways**, with different resources configured in ways that were specific, and entangled, with their localities. If we were to look across each of these railways, they would be recognisable as like each other, but they would all have unique differences specific to their local place.

The fifth loop (links and knots) at the centre of the theoretical model (Figure 5.1) is a conceptual element that ties the other loops together and this collective network acts as a train. To understand what is holding these diverse collections of resources together at this point in history, then I propose that this central loop (loop 5, links and knots) is very much about the concept of **a local railway**. The multiplicity of railways that appear at this time are all like each other, and all act as railways, but they are all configured in a close relationship with their locality. At this stage in the development of railways, the links and knots holding each railway together is explained by the local human and natural geography. Railways operating in areas with steep gradients have locomotives with a recognisably different form to others operating in flatter areas. For example, the London and North Western Railway (L&NWR), operating in the 19th century, had to cope with the hilly country north of Lancaster and their locomotives were visibly larger than the Midland Railway operating in geography with shallow gradients. The action of the non-human, in the form of gravity and gradients, upon the body of the locomotive was easier to see in this early stage of the railways, before increasing engine power overwhelmed this influence.

This diverse multiplicity of local railways also inevitably included 'mistakes,' inefficiencies, and problematic outcomes. One example, in 1837, came from none other than I. K. Brunel, the Engineer of the Great Western Railway (GWR), among other notable achievements. While the Great Western Railway was being built, he issued a specification to several different manufacturers to build the first locomotives for the new railway. Like the Rainhill Trials, we have a representation of desired locomotives in a written specification, and a request for suppliers to respond to these requirements with their propositions. However, the realised trains produced by this action were "an extraordinary collection of freak locomotives," (Adams, 1993, p.

114). This actor-network to produce trains included one of the greatest engineers of the time, but this was no guarantee of a successful outcome.

Despite problems, there were many improvements over early configurations. For example, early passenger vehicles followed closely the style of horse-drawn stagecoaches, as illustrated by GWR passenger rolling stock, shown in Figure 5.4 below.

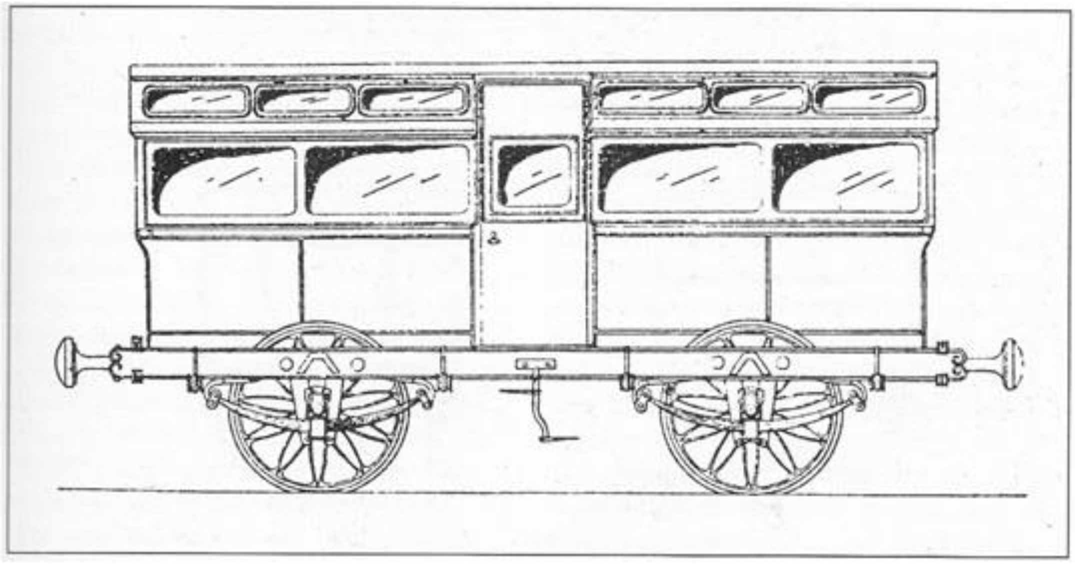


Figure 5.4 GWR 'Posting Carriage' for passengers in the 1840s

Source: (Adams, 1993, p. 183)

This early four-wheeled carriage could jump the track at speed (Adams, 1993, p. 184) and so Brunel built carriages with six wheels and three axles. This meant longer bodies and heavier vehicles, but weight also *acted* to provide greater stability at speed. As the railways improve upon designs borrowed from other professions, such as stagecoaches, the railway profession becomes specialised and distinct (loop 2, autonomisation) and this expertise strengthens the network.

The growth of local railways accelerated. In 1846 there were 272 Acts of Parliament, which authorised “9,500 miles of new railway” (Holland, 2015, p. 6). The **names of the railway companies from this time illustrate how connected they were to their local geographies.** The Leicester and Swannington Railway opened in 1832, the Ulverston and Lancaster Railway opened in 1857, and many more. A list of more than 200 companies from this time is shown in Table 9.1 in the appendix. These private organisations were driving the expansion of the railways “from the choice of routes and the raising of capital to the operation of services” (Gourvish, 2008, p. 49).

A writer in 1885 noted the “stupendous” (Williams, 1885, p. 468) amount of £831 million pounds (c. £107Bn[6] in 2019) of capital provided by private shareholders, and authorised by Acts of Parliament, to build, maintain, and enlarge the network. Not all schemes were built, but a lot did progress and, by 1880, 75% of the eventual rail network was built. The first of the descriptive statistics is used here to help tell this story. The length of railway track is shown in Figure 5.5 below, for the period up to 1880. The data is first available from c. 1830, when the Liverpool & Manchester Railway opened.

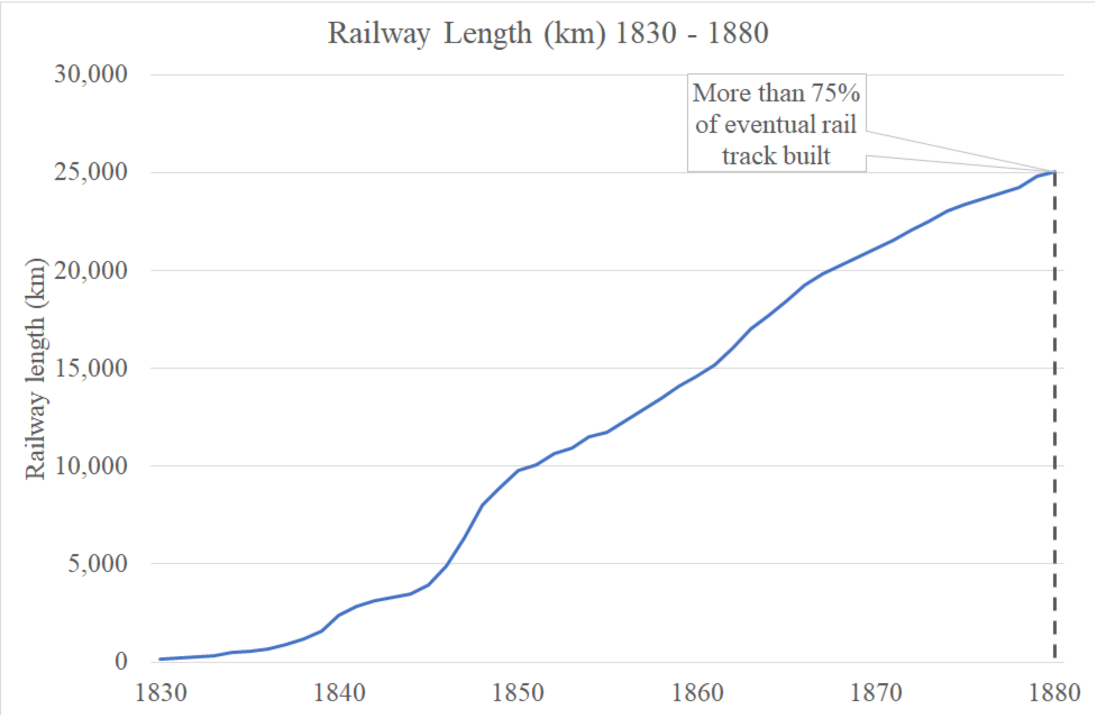


Figure 5.5 The length of the railway in Britain (1830-1880)

Source: (Mitchell, 1988, pp. 541–542, table 5) and my own analysis

This chart (Figure 5.5) shows 25,000 km of railway in place by 1880 – a compound annual growth rate of 11% per year for the period 1830 to 1880, which meant that the rail network was doubling in size approximately every seven years. Wherever the railway went it reached out to form alliances (loop 3) because it was also a significant construction enterprise, creator of opportunities, and provider of employment (loop 4, public representation). To take one example, Railway Engineers (loop 2, autonomization) built “an average of 1,000 bridges” (Johnson and Long, 1981, p. 7) every year between 1830 and 1860.

[6] Bank of England Inflation Calculator: https://www.bankofengland.co.uk/monetary-policy/inflation/inflation-calculator

Government was an actor in each local railway through supporting Acts of Parliament, but it also introduces legislation that affects and acts upon all railways. In 1840, the Railway Regulation Act (Her Majesty's Government, 1840) included the establishment of Her Majesty's Railway Inspectorate (HMRI) as a body to oversee safety. In 1844 the Railway Regulation Act (Her Majesty's Government, 1844), referred to as Gladstone's Act after William Gladstone, introduced various measures beyond safety, including the ability to control railway charges, and purchase future railways for the state. The 1844 Act also introduced a requirement for operators to provide inexpensive and basic rail transport. These trains, referred to as *parliamentary trains*, were required to carry third class passengers at minimum standards of comfort, including protection from the weather, at least once per day, at specified minimum speeds with fare rates capped. Not all operators supported this and "GWR was forced, much against its will, to provide carriages for the 'lower orders,' which gave some protection from the elements" (Adams, 1993, p. 184). However, in 1872, the Midland Railway agreed to run third-class carriages on all trains (Williams, 1885, p. 389), above and beyond what was required by the 1844 Act. This change was introduced by the General Manager, James Allport. In 1875 he abolished second class on all of the Midland's trains (Wolmar, 2007, p. 132), ensured that all seats were upholstered, provided more leg-room for passengers, and introduced further improvements to the travelling experience for the passenger (loop 4, public representation). The success of this strategy would see it adopted across the railway and, by 1881, third class accounted for more than 80% of all passengers and 65% of all receipts across the railways. The changing responses of operators to Gladstone's Act can be viewed as a clash of different concepts of the railway (loop 5, links and knots), with the Act moving rail towards **a national mass transit service**.

During this period, rail was competing with road, canals, and coastal shipping. Poor quality roads were not an enjoyable experience for passengers, and often caused damage to goods. These other options could also be very slow, for example the 29-mile journey on the Worcester & Birmingham Canal, which opened in 1815, involved passing through 58 locks and four single-lane tunnels, with journeys sometimes taking a couple of days (Holland, 2015, p. 15). By contrast, the specialist technology of the railway (loop 2, autonomization) was improving all the time strengthening the actor-networks that acted as trains. For example, steel rails replaced iron in the 1860s (Gourvish, 1980, p. 25), enabling increasing speeds and quality of service. Stephenson's Rocket achieved a top speed of 29 mph in 1829, but this was surpassed in 1846 by a speed of 74 mph, then 90 mph by 1897. High profile races took place between different operators, with marketing campaigns showing trains transporting people to new tourist locations. Train speed reaches out and captures the public imagination (loop 4, public representation) and is a visible demonstration of the expertise of engineers (loop 2, autonomization). Some Chief Engineers become household names.

The railway's speed and smooth running was creating new commercial opportunities (loop 3, alliances; and loop 4, public representation) that begin to transform society, with these loops further strengthening the railways. For example, journalists were now able to send intelligence quickly to London for morning papers (Lardner, 1850, p. 39) from correspondents across Europe, and physical newsprint could now be widely communicated. Perishable goods – meat, fish, fresh milk and vegetables – could be transported (Gourvish, 1980, p. 31) to cities with minimal breakages and losses, reaching their destination faster and fresher. Figure 5.6 below shows a specific vehicle created for fish traffic (loop 3, alliances) from Fleetwood dock, which opened in 1877 and became a major industry in 1890.

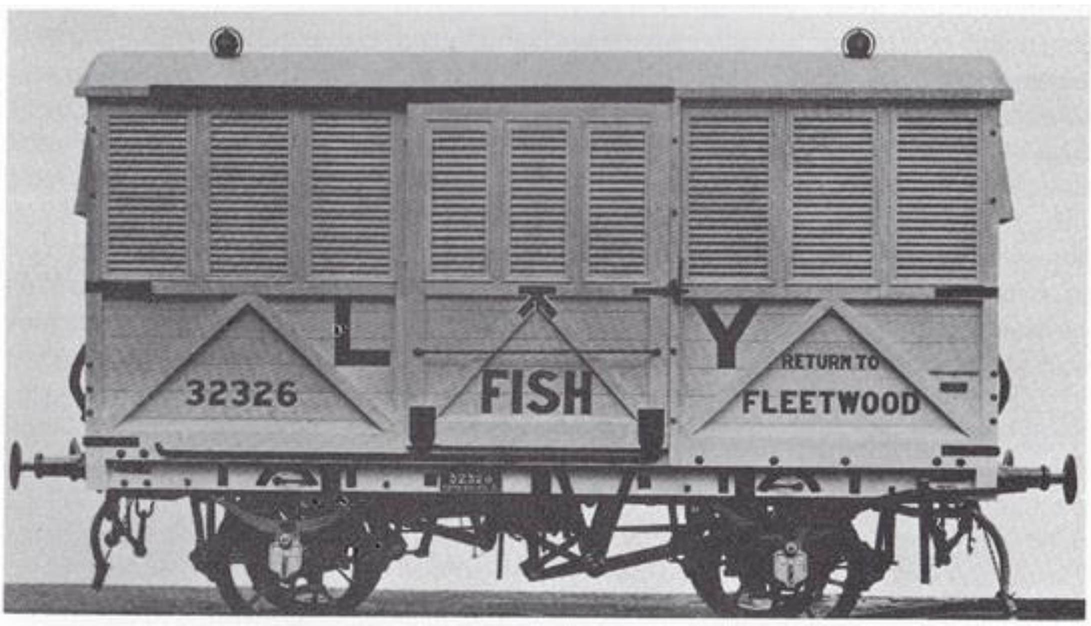


Figure 5.6 Lancashire & Yorkshire Railway fish van for Fleetwood Dock

Source: (Simmons, 1987, p. 235)

In Great Britain and beyond railways forged unified national markets, linked domestic producers to the expanding world economy, facilitated the development of mass-production techniques, and incubated modern management practices (Eichengreen, 1995). The success of the railways is illustrated by the second of the descriptive statistics used to help tell this story: industry receipts (income) for passengers and goods (see Figure 5.7 below).

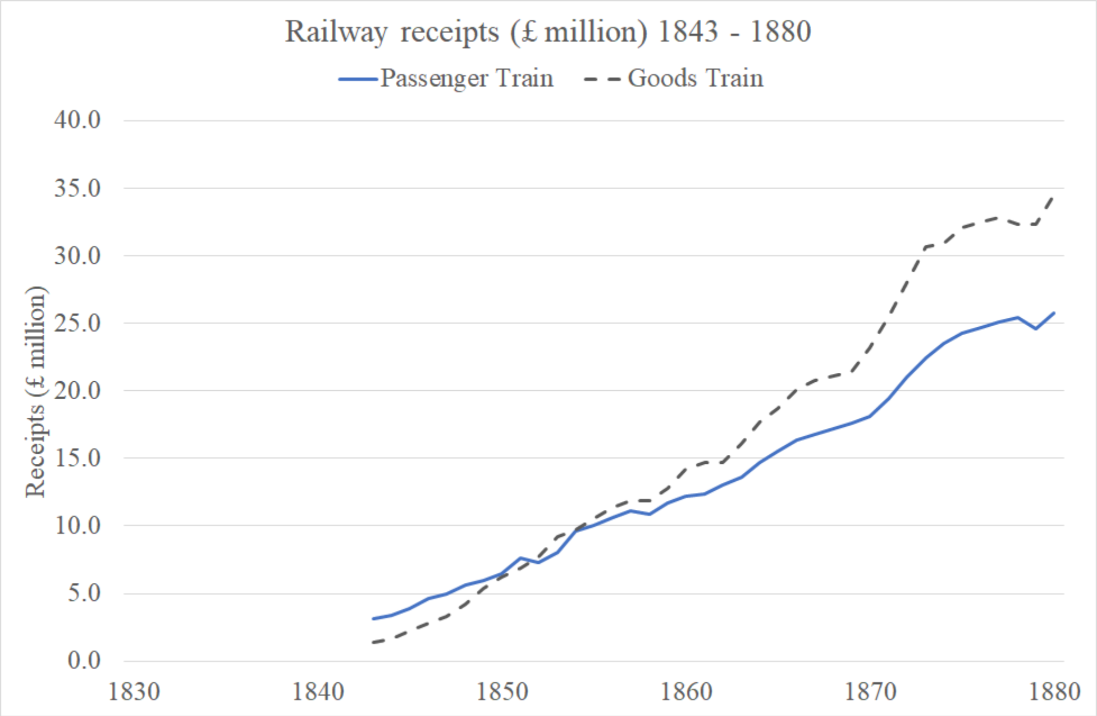


Figure 5.7 Historical growth of rail receipts for passenger and freight services in Britain

Source: based on (Mitchell, 1988, pp. 545–550, table 7) and my analysis

The chart shows receipts from passenger and freight services from 1843, when data is first available, through to 1880, up to the same period as the previous chart showing the length of railway track. The mixed use of the railway is visible in this chart, with freight income larger at the end of the period. Between 1843 and 1880 passenger receipts saw 6% compound annual growth and 9% for goods. This meant that passenger railway income was doubling approximately every 12 years and freight income every eight years.

An author writing in 1885 illustrates the high regard of the railways at this time, when he says that, “every mile of every railway…has at almost every stage enriched somebody, has enriched the nation and the world” (Williams, 1885, p. 498). Despite this positive regard for the railways, there were still problems, and safety concerns especially would prompt Government action. The Regulation of Railways Act of 1868 (Her Majesty's Government, 1868) introduced various impositions and powers related to the railways, including a measure to improve passenger safety using a "Means of Communication between the Passengers and the Servants of the Company in charge of the Train" (Her Majesty's Government, 1868, p. 1165). At this time there was no way to move safely between cars, or to contact the driver, in the event of a problem, therefore legislation acted upon the configuration of resources that make up a train. A cord or chain was required that could be pulled by a passenger in an emergency. The communication cord had to run the full length of the train, but this proved a technical challenge at the time because this length can change, depending upon if the train is travelling in a straight line or following a curved section of the route. Making the cord too short could lead to it snapping, whereas too much slack would make it difficult for passengers to alert the driver. The mandated requirement for a train cord proved to be a "patently unsatisfactory method…[and was] withdrawn five years later" (Gourvish, 1980, pp. 51–52). Instead, operators were required to propose their own systems for approval, with a fine levied for inaction. Legislation still acted upon the train actor-network, but as a penalty for inaction rather than a prescription of how to configure resources and act.

Government introduced further safety legislation after a rail disaster on 12 June 1889, near Armagh in the North of Ireland, in which 80 people died and 260 were injured. A crowded Sunday school excursion train, pulled by a steam locomotive, was unable to climb a steep hill. The train crew decided to divide the train, to reduce weight, and then use the locomotive to take forward the front portion, leaving the rear portion on the running line until the locomotive returned. Tragically, the rear portion was inadequately braked and ran back down the gradient, colliding with another train. Braking technology had been developing but was not uniformly applied across all trains. The Regulation of Railways Act 1889 (Her Majesty's Government, 1889) required a single operator, the driver or guard, to be able to activate the brakes on every vehicle of the train. This Act also made the use of *interlocking* of points and signals compulsory, so that it is impossible to display a signal to proceed, unless the route to be used is safe for travel. Another key safety requirement was for the railway companies to adopt the *block system*, with a route broken up into a series of blocks, with only one train permitted to occupy a block at a time. The block system and interlockings remain central safety components in the action of the modern railway. By the late 19th century improved safety equipment was widely used across vehicles and infrastructure.

Passenger fatalities were terrible, but those working on the railway were subject to extreme rates of death and injury – with 742 men killed and 3,500 injured in 1874. Long working hours were an important contributing factor to accidents and fatalities, with employees often working a 60-hour week (Gourvish, 1980, p. 54). The Amalgamated Society of Railway Servants (ASRS) had 38,000 members in 1895, 98,000 in 1907, and 273,000 members in 1914, when it was known as the National Union of Railwaymen. Increasing tussles took place between employees and employers, with strikes during the late 19th and early 20th century. In August 1911, the ASRS and other unions jointly called the first national rail strike. The increased strength of organised labour was demonstrated again in 1919 with a 9-day strike in response to government proposals to reduce rates of pay. This also "provided the first impetus to the development of competitive road transport" (Fenelon, 1933, p. 383).

A growing dissatisfaction with the railways was beginning to develop. The bursting of the earlier railway mania bubble had given way to a recognition that new railways, especially those built to serve the local needs of small communities, could not be built economically, with fare revenue unlikely to justify capital cost. Not everyone cared about the economics of the railway, however, as illustrated by a trader in Berwick on the borders of England and Scotland who said, c. 1890,

> *"What we want is to have our fish carried at half present rates. We don't care a ____ whether it pays the railways or not. Railways ought to be made to carry for the good of the country, or they should be taken over by the Government. That is what all Traders want and mean to try to get." (Tatlow, 1920, p. 104)*

The early railways had been strengthened because their loops reached out to many different parts of society. This had been a critical enabler of early growth and success, but the railway's importance to other industries and parts of society was leading to competing conceptions of the railway (loop 5, links and knots) and its purpose. A railway configured to run for the benefit of fish traders, and other industries, has a different conception at its centre (loop 5, links and knots) than a railway designed to run for, say, passengers, or shareholders. Different conceptions at the centre (loop 5, links and knots) will all act as railways, but they will lock in different resources into the network and so have different attributes and characteristics in how they act as railways. Questions were being asked about who should benefit from railway services, who should pay the costs, and how the railways should be organised.

After 1880 the early frantic growth began to plateau and the railways entered a mature stage (Gourvish, 1980, p. 41), as illustrated in Figure 5.8 below, which updates the chart shown earlier for the length of railway track built.

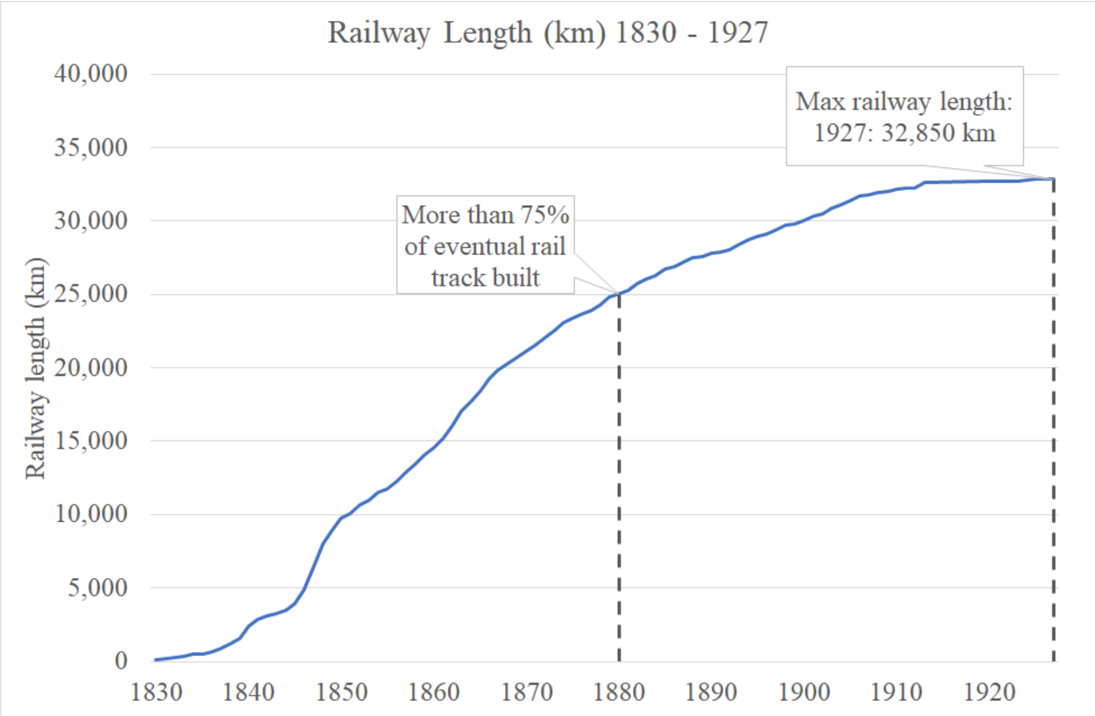


Figure 5.8 Historical growth of the railway in Britain – the length of the railway (1830-1927).

Source: based on (Mitchell, 1988, pp. 541–542, table 5) and my analysis

New railways were still being built after 1880 and the length of the rail network increased, however, the steepness of the graph eased off, reflecting a reduced growth rate of 1% per year between 1880 and 1927, as construction activity slowed. Growth would eventually stop in 1927, when the railway reached its maximum length of 32,850km. The extent of the physical network has never been greater and would reduce in length in future years.

Although construction of the physical network was slowing after 1880, the use of that network continued to grow. This can be demonstrated using the third descriptive statistic, which measures the number of passenger journeys on the railway. This statistic could mean more people using the railway, or people using it more often, or some combination. The number of passenger journeys is shown in Figure 5.9 below, with the point in 1880 noted when 75% of the physical rail network was built, and 1927 also marked when the physical rail network reached its largest ever size.

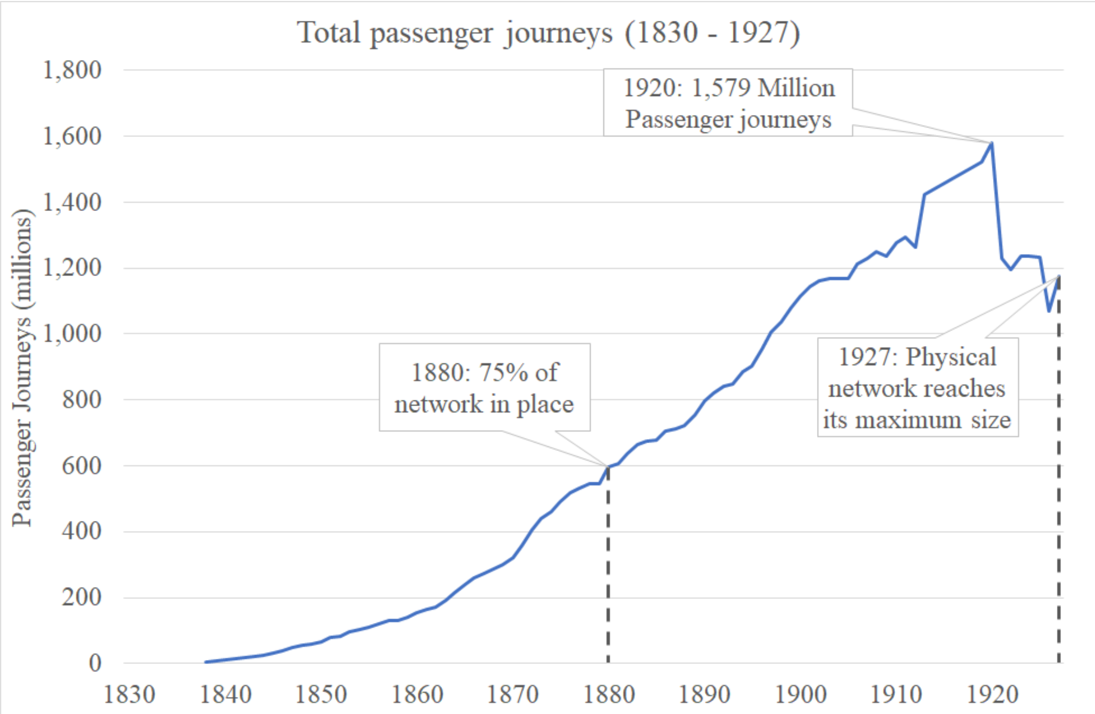


Figure 5.9 Historical growth of Rail Passenger Journeys in Britain (1830-1920)

Source: based on (Mitchell, 1988, pp. 545–550 (table 7)) and my analysis

Between 1843 and 1880 passenger journeys were growing at a compound rate of 9% per year, which meant a doubling of passenger journeys every eight years. From 1880 to 1913, before the start of World War One, the growth of passenger journeys continued to grow at 3% per year. Passenger journeys reached a maximum of 1.6 Billion in 1920, nearly treble the figure for 1880. This number of passenger journeys would not be surpassed again until the year 2013.

The increasing maturity of the railway was evident in ongoing consolidation within the industry. By 1906, 233 of the 351 companies that existed in 1881, had closed or been absorbed by larger rail organisations (Aldcroft, 1968, p. 8). The earlier actor-networks of local railways are giving way to railway organisations that are enormous enterprises, with vast operations in place to produce trains and deliver the railway service. For example, in 1875 the Midland Railway Company could produce trains at their site in Derby, which employed 2,000 men, had a sawmill, wagon-shop, carriage-shop, painting and trimming shop (Williams, 1883, pp. 364–365).

The industry were already consolidating but the First World War produced a “form of quasi-nationalisation” (Murray, 2001, p. 4). The railways were to be “managed as a single system” (Bonavia, 1980, p. 9) under the unified control of a Railway Executive Committee (REC), consisting of the General Managers of the largest railway companies. This government body was set up in 1912 to act as an intermediary between the War Office and the various railway companies. On 4 August 1914, “unified control was imposed by the Railway Executive Committee” (Grieves, 1989, p. 10) to ensure prioritisation of military traffic, to avoid duplication, and save resources. During World War One a new concept of the railways (loop 5, links and knots) meant that “utility replaced glamour” (Bonavia, 1980, p. 95) in how the railways were enacted. This concept meant a focus upon heavy train loads, a reduced speed limit of 60 mph, cleaning was abandoned, and maintenance reduced.

The combination of industrial action, regulatory interventions over time, including an eight-hour working day, and government’s control of the railways during the First World War, meant that “Government intervention, once piecemeal and lukewarm, had penetrated all areas of managerial activity” (Gourvish, 1980, p. 54). By 1921, a combination of increased costs and Government’s refusal to allow charges to be raised, would lead to the first loss for the industry. This is illustrated using the fourth and final descriptive statistic to help tell this story. Figure 5.10 below shows railway income, expenses, and resulting profitability for the period 1853 to 1921.

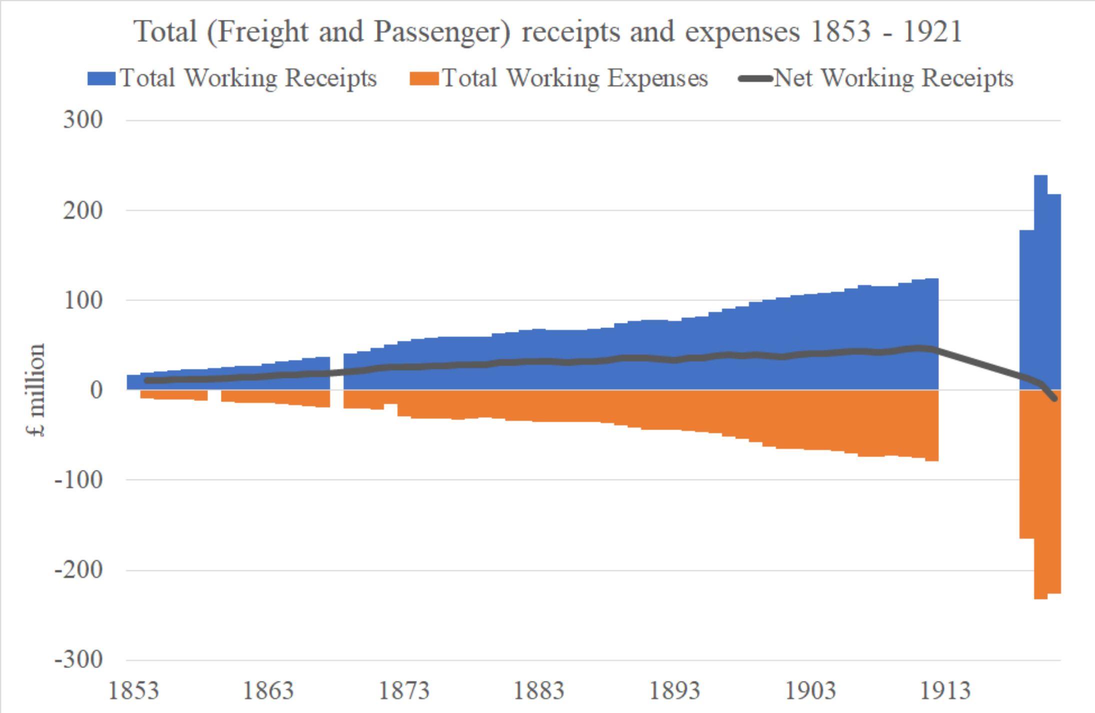


Figure 5.10 Total (Freight and Passenger) receipts, expenses, and profitability 1853 – 1921.

Source: based on (Mitchell, 1988, pp. 545–550 (table 7)) and my analysis

The chart above shows the receipts of the railway, from both freight and passenger traffic, as a bar chart, with a gap during World War One. Income is shown above the line as a positive value, and it is growing over time. Expenses are shown as a negative value below the line, and they are also growing over time. The net-working receipts of the railway (income – expenses) is shown as the black solid line. In 1921, for the first time in its history, rail industry profitability moved negative – industry costs were greater than income from passenger and freight traffic. This is the total income for the railway, rather than individual lines, some of which were loss-making, some profit-making. Profitability is shown here as an absolute value, however if it were shown as a percentage, then the railway's profitability, from the 1850s to the end of the 19th century, was in the 40-50% range i.e., income was 40-50% greater than costs. This illustrated the large returns possible in the early growth stage and why railway mania took such a grip.

The railway was vitally important to the nation and British Railways were still "generally considered the best in Europe, if not the world" (Bonavia, 1980, p. 7). However, the conditions were developing for a significant change. The railways' deficit for 1919-20 was £41M (£2 billion at 2019 prices) and was estimated to become £54.5m the following year (Adams, 1993, p. 92). The growth of private motor vehicles was also about to challenge the dominance of rail, with freight first to bear the brunt when soldiers returned from war and bought former military lorries that were released for use as private goods vehicles. Operating the railway as a single system during World War One, and the industry's negative financial position, might have pointed towards nationalisation as the answer. Indeed, Winston Churchill gave a speech saying that "…it might pay the State to run railways at a loss to develop industries and agriculture" (Bonavia, 1980, p. 11). However, nationalisation was not chosen, instead the government White Paper (His Majesty's Government, 1920) proposed a grouping of railway undertakings.

Among other measures, the White Paper contained a proposal for Worker Directors on the Board of Management of the new grouped organisations: "the Government are of the opinion that the time has arrived when the workers – both officials and manual workers – should have some voice in management" (His Majesty's Government, 1920, p. 2). Sir Eric Geddes, the first ever Minister of Transport, was said to have "personal enthusiasm for worker participation at Board level…to promote a fuller awareness in the workforce of the commercial implications of pay awards" (Grieves, 1989, p. 90). However, the companies viewed it as "unwarranted interference in the right of companies to choose a Board" (Grieves, 1989, p. 90). Railway trade unions were against minority representation, preferring state ownership, so the two groups jointly acted to "persuade the Government to drop the plan for worker directors" (Wolmar, 2007, p. 225) from the legislation. Competing conceptions (loop 5, links and knots) of railway organisations to deliver railways are playing out.

The subsequent Railways Act of 1921, also known as the *Grouping Act*, sought to achieve a "reorganisation and more efficient and economical working of the railway system" (His Majesty's Government, 1921, p. 1). This next era, between 1923 and 1947, was the time of the *Big Four*, dominated by the four largest railway companies. The new conception of the railway (loop 5, links and knots), driven by legislation, was a work in progress.

5.2 The era of the Big Four

In 1921 there were 214 separate railway companies (Fenelon, 1933, p. 383), of which 120 were to be amalgamated by the Railways Act into four groupings (His Majesty's Government, 1921, p. 69, First Schedule):

1. The Southern Group – known as the Southern Railway (SR)
2. The Western Group – known as the Great Western Railway (GWR)
3. The North Western, Midland, and West Scottish Group – known as the London, Midland and Scottish Railway (LMS)
4. The North Eastern, Eastern, and East Scottish Group – known as the London and North Eastern Railway (LNER)

Table 9.2 in the appendix (page 315) sets out the list of 120 companies that made up the four groupings, including 27 larger railways identified as *constituents,* and 93 smaller railways identified as *subsidiary* companies. Some railways, such as the Liverpool Overhead Railway, remained outside of the grouping, but the Big Four organisations accounted for 95% of total route mileage. The Act took effect on 1 January 1923 and the period from 1923 to 1947 became known as the era of the *Big Four*. The earlier railways were a diverse mix that reflected the places in which they were located and operated. Industry consolidation was already changing this, but the railways now were being forcibly shaped by the Act with large and small railways combined.

The LMS Railway was the largest of the Big Four by size of network and "was Britain's largest commercial enterprise" (Johnson and Long, 1981, p. 3). It employed 275,000 people, owned 10,000 steam locomotives, 20,000 passenger carriages, 207,000 freight wagons and 9,000 horses (Wolmar, 2007, p. 232) across 7,331 route miles (11,798 km) between London, the North West of England and Glasgow in Scotland. LNER was the second largest, with 6,671 route miles (10,736 km) and control of the East Coast, including London to Edinburgh. The Southern Railway was the smallest with 2,115 route miles (3,403 km), but the largest operator of passenger services with busy commuter services to London. Although the Big Four were in private ownership, Government played a significant role in the production of the railway, through standardised wages, conditions, and other regulations.

The groupings were the most visible feature of the Railways Act, but its primary aim was the "quest for financial stability in the industry" (Grieves, 1989, p. 92) in response to the first ever industry loss in 1921. The rail network reflected this quest for stability, with new track growth relatively flat and reducing slightly after peaking in 1927, as illustrated by the updated chart showing the length of rail track in Figure 5.11 below.

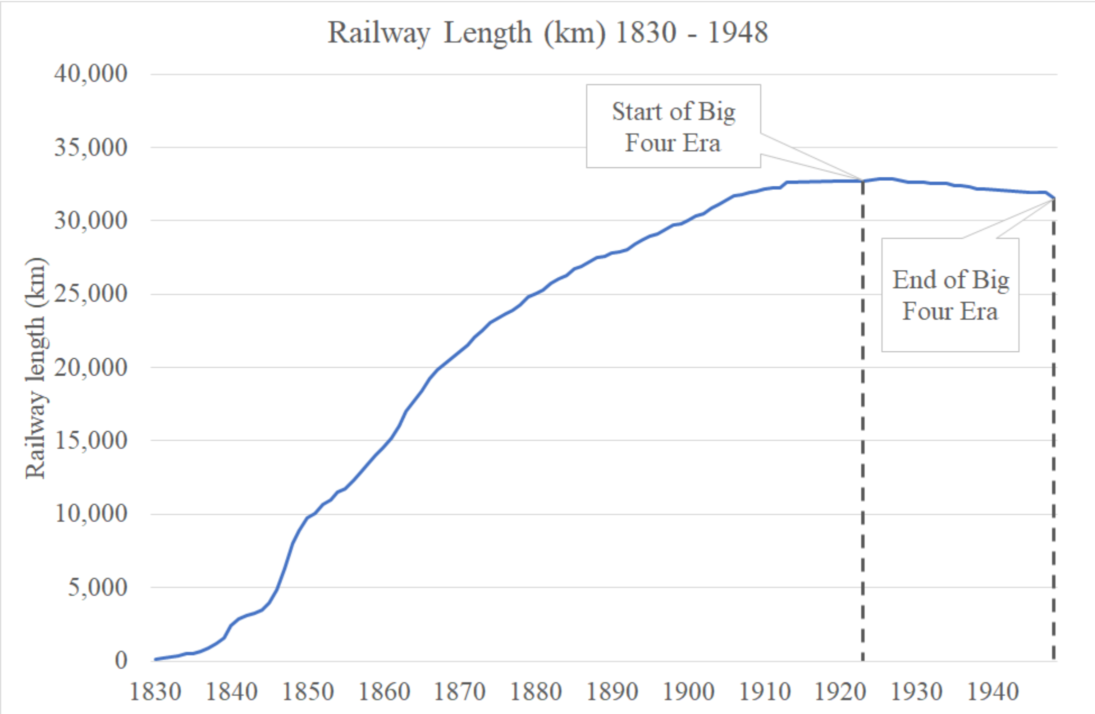


Figure 5.11 Historical growth of the railway in Britain – the length of the railway (1830-1948).

Source: based on (Mitchell, 1988, pp. 541–542, table 5) and my analysis

To recover from World War One the new railway went on a drive for greater efficiency, which led to consolidation and standardisation around train designs and practices within the profession (loop 2, autonomization). However, this standardisation was not necessarily about the 'best' designs wining out. The existing engines of smaller *constituent* companies within the groups, were scrapped in the first 10 years after grouping (Bonavia, 1980, p. 27). New orders were aligned with the views of dominant organisations within the groups and the smaller railways struggled to gain a voice relative to their larger peers. For example, the Western Group was dominated by the Great Western Railway Company with 4,836 km of route, compared to its largest fellow constituent company, the Cambrian Railway, which had 475 route km. The 26 smaller *subsidiary* companies within the Western Group had even smaller railways and less voice. The other three groupings did not have one large organisation like the Western, instead they contained several large railway organisations (appendices, Table 9.2 on page 315) and these companies were not always natural partners, given their geographies and history. The Big Four organisations were “artificial constructs formed by legislation” (Wolmar, 2007, p. 228).

A new concept of trains and the railways (loop 5, links and knots) was being forged and developed within each of the groups. Each of the Big Four railway organisations were recognisably like each other, but there were also different conceptions of how railways and trains should be configured. Early railways were strongly influenced by local geography, whereas now differences were more likely to reflect the dominance of different organisations within the groups. An organisation with a large railway but a flat and urban terrain could have greater influence over the concept of how railways and trains should be configured, than a smaller railway with a hilly rural geography. Consolidation did not produce standardisation across the industry, with each of the Big Four maintaining their own ways of delivering a railway service and producing new trains (loop 5, links and knots).

Although each of the Big Four operated mostly within their own geographies, there was a strong rivalry to claim technical leadership. Development of the railways and new trains was led by Chief Mechanical Engineers (loop 2, autonomisation) within each of the Big Four. During the Big Four era these engineers produced world-leading designs and competed to reach ever higher speeds. The “publicity value” (Bonavia, 1980, p. 93) of this was fully exploited in supporting advertising campaigns (loop 4, public representation). This reached a peak on 3 July 1938, when the *Mallard* (see Figure 5.12 below) of LNER set a world speed record for steam of 126 mph (202.8 km/h).

Figure 5.12 Gresley's 'A4' No. 4468 Mallard

Source: (Holland, 2015, p. 197)

Sir Nigel Gresley, who built *The Mallard*, was the Chief Mechanical Engineer (CME) for LNER Railway from 1923 to 1941. *The Mallard* weighed 240 tons in total (Holland, 2015, p. 197), which included six coaches and a dynamometer car to measure speed (loop 1, mobilisation of the world) and other variables, so that Mallard's achievement could be validated and communicated around the world. The locomotive and its tender (for carrying coal) accounted for 165 tons of the total train weight. For comparison, *Rocket* and its tender car weighed about seven tons at Rainhill in 1829. Unfortunately, *Mallard* had to come off at Peterborough instead of continuing to London, because a bearing over-heated. However, a new concept of the railways (loop 5, links and knots) can be discerned in this *Big Four* battle for speed and technical dominance. This **new concept saw the railways as technical and engineering masters, with the CMEs becoming household names and embodying this mastery.**

The early period of the Big Four included the financial crash of 1923, General Strike of 1926, and the Great Depression from 1929-1932. Despite these events, passenger numbers stabilised after the war, and the industry returned to profitability with a rail network that was slightly reduced in size. The earlier railway reached out and formed alliances (loop 3) with many industries and connected positively with the public (loop 4) in many cities, towns, and villages. However, these loops that had strengthened the railway actor-network were beginning to weaken. A significant source of new competition to rail's dominance was coming from the growth of the private motor car and goods vehicles.

The growth of goods vehicles had begun after the first World War, when the government sold off large numbers of military vehicles. Many were bought by returning soldiers, trained to drive them during their service. Road hauliers were not subject to *common carrier* regulations, which dated from the 19th century legislation and the Railways and Canal Traffic Act (His Majesty's Government, 1854). Common carrier regulations, established when the railways were effective monopolies, required them to carry any goods at nationally agreed rates. This legislation now allowed private goods hauliers to cherry pick profitable services, with the railways unable to act until these responsibilities were lifted many years later.

Rail was still able to offer passengers a faster service than the private motor car because motorways did not appear until the 1960s, with the opening of the M1 on 2 November 1959 (Merriman, 2007, p. 106). The level of comfort on the railway had improved significantly from the early days when passenger coaches were no more than open carts for third class passengers. Trains often had compartments with a much-improved level of comfort, even in 3rd class, as shown in Figure 5.13 below for a carriage that began operations during the Big Four era.

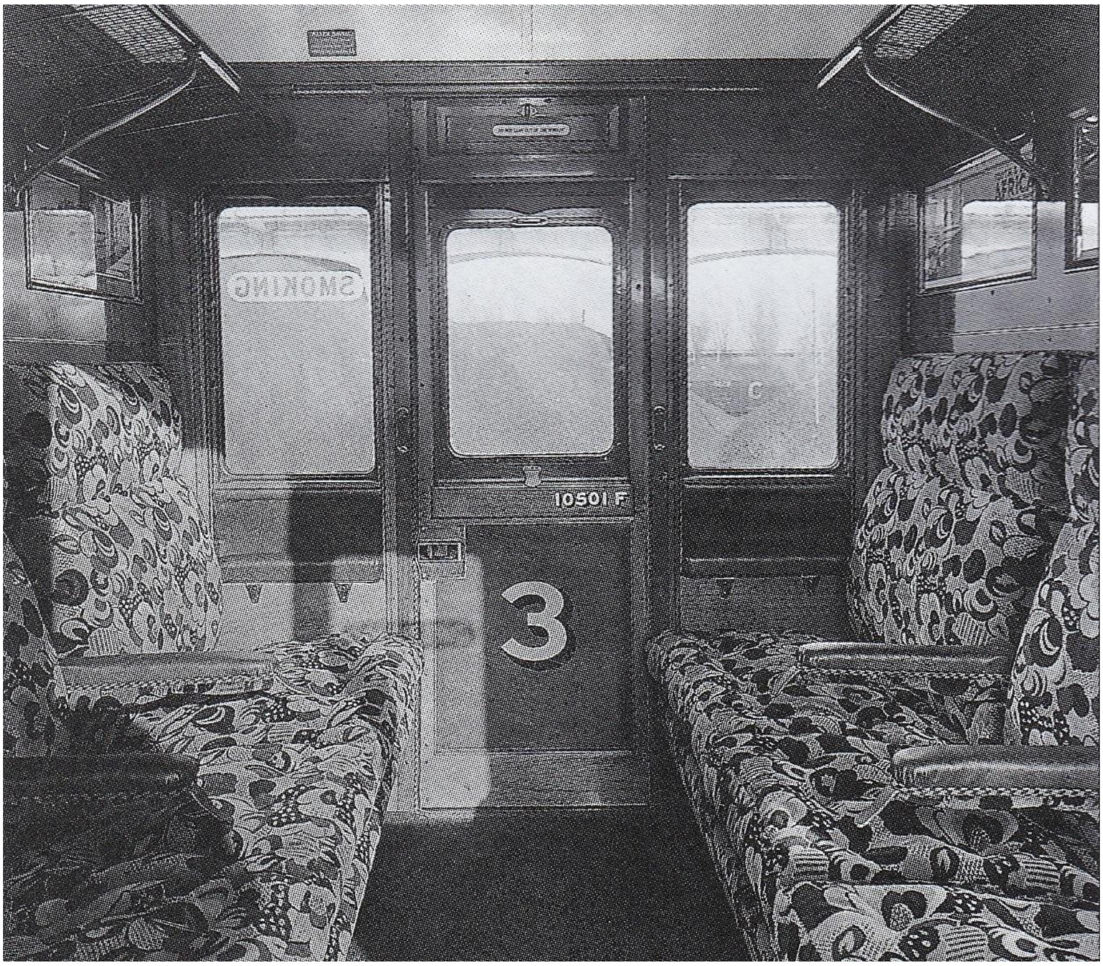


Figure 5.13 Third class comfort in a carriage operating c. 1930-1968

Source: (Robertson, 2005, p. 22)

Improving passenger comfort and other attributes was influencing train design, but so were passenger numbers and the requirements for extra capacity. In response to this Oliver Bulleid, Chief Mechanical Engineer (CME) of the Southern Railway, designed a double decker train (Figure 5.14 below), that could still fit within the rail network's *loading gauge* to navigate tunnels and other infrastructure. These double deck trains were discontinued because passengers in the upper compartments could feel trapped, and the time taken to load, and unload trains, was significantly longer.

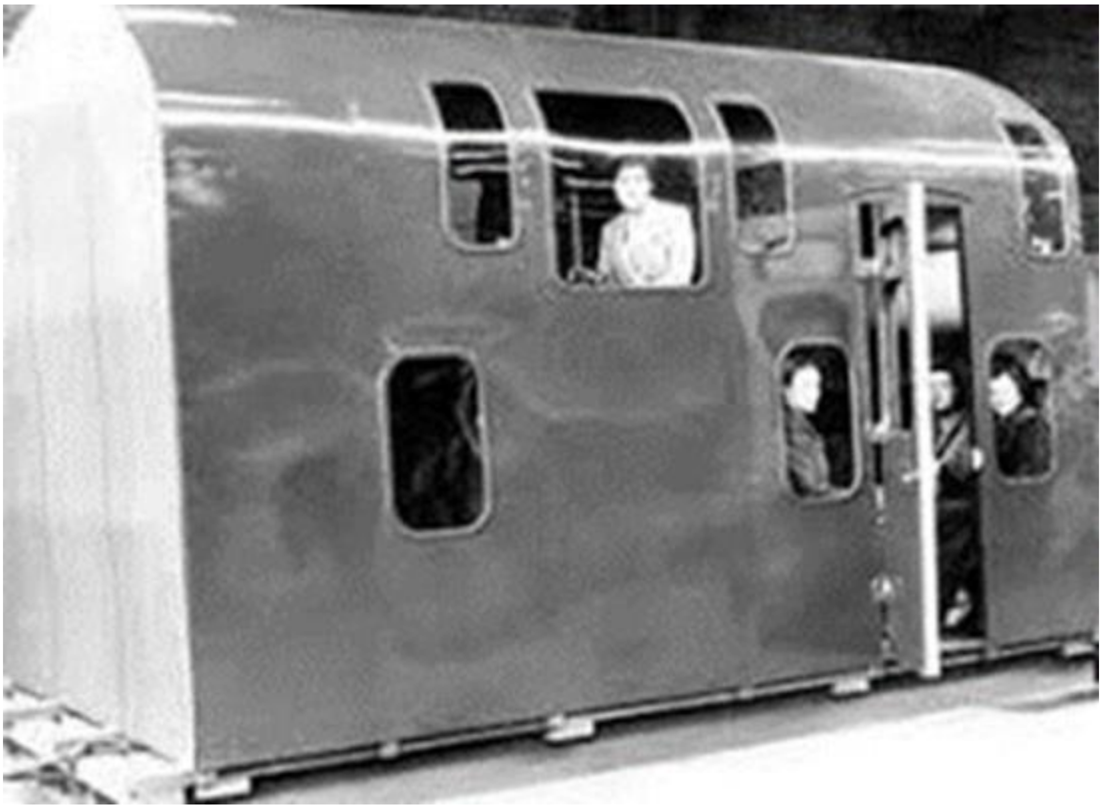


Figure 5.14 Double Decker train designed by Oliver Bulleid for the Southern Railway in 1949

The Big Four era can be viewed as a period of technology mastery, with CMEs and organisations with long-established technical expertise in the production of steam-powered trains. However, war would once again bring change to the railways and make it difficult to judge the success, or otherwise, of the Big Four companies.

Figure 5.15 below shows that industry income from passenger and freight traffic (the 2nd descriptive statistic used through this chapter) grew at an average of 2% per year between 1923 and 1948. The chart shows a significant spike during the Second World War, which most likely reflected use of the railway for war-time operations.

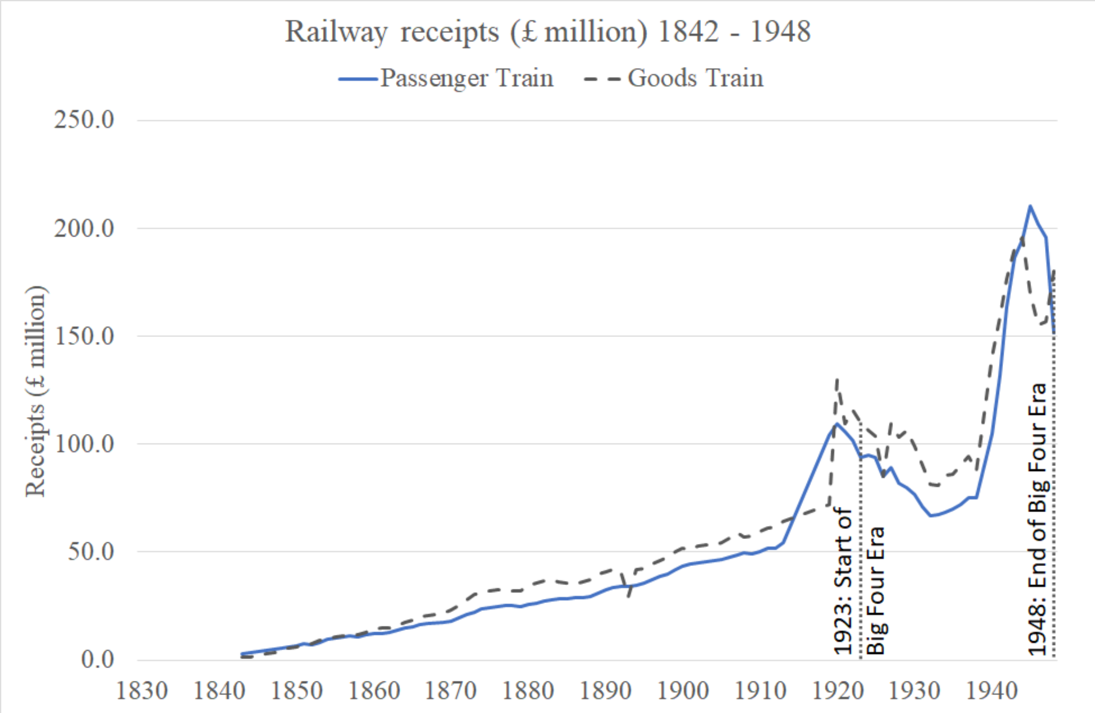


Figure 5.15 Historical growth of rail receipts for passenger and freight services in Britain (1842 – 1948)

Source: based on (Mitchell, 1988, pp. 545–550, table 7) and my analysis

Figure 5.15 (above) does show an increase in income during the Big Four era from 1923 to 1948. However, the third descriptive statistic used in this chapter, which measures the number of passenger journeys, provides a different perspective on the changes underway in the railway. This statistic, measuring passenger journeys, is shown in Figure 5.16 below.

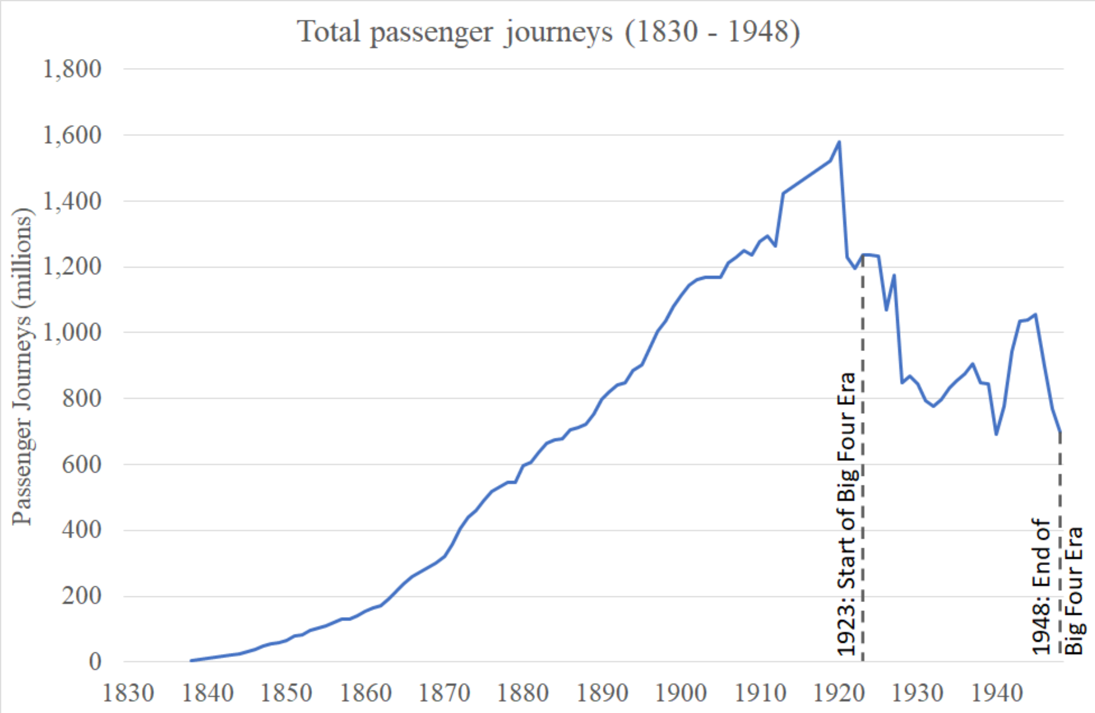


Figure 5.16 Historical growth of Rail Passenger Journeys in Britain (1830-1948)

Source: based on (Mitchell, 1988, pp. 545–550, table 7) and my analysis

This chart (Figure 5.16 above) shows the rapid growth in passenger journeys during the first phase of the railways, which peaks at 1.5 billion in 1920. When the Big Four Era began in 1923, there were 1.24 billion passenger journeys, but this had reduced to 700 million at the end of this period in 1948 – a reduction of over 2% each year. The reasons behind this are explored shortly.

A key goal of the Grouping Act was to address industry losses and stabilise the industry through consolidation. The creation of the Big Four did initially achieve this with a return to profitability early on, as shown in Figure 5.17 below. However, by the end of this period we see profitability turning negative again in 1947, with expenses greater than income.

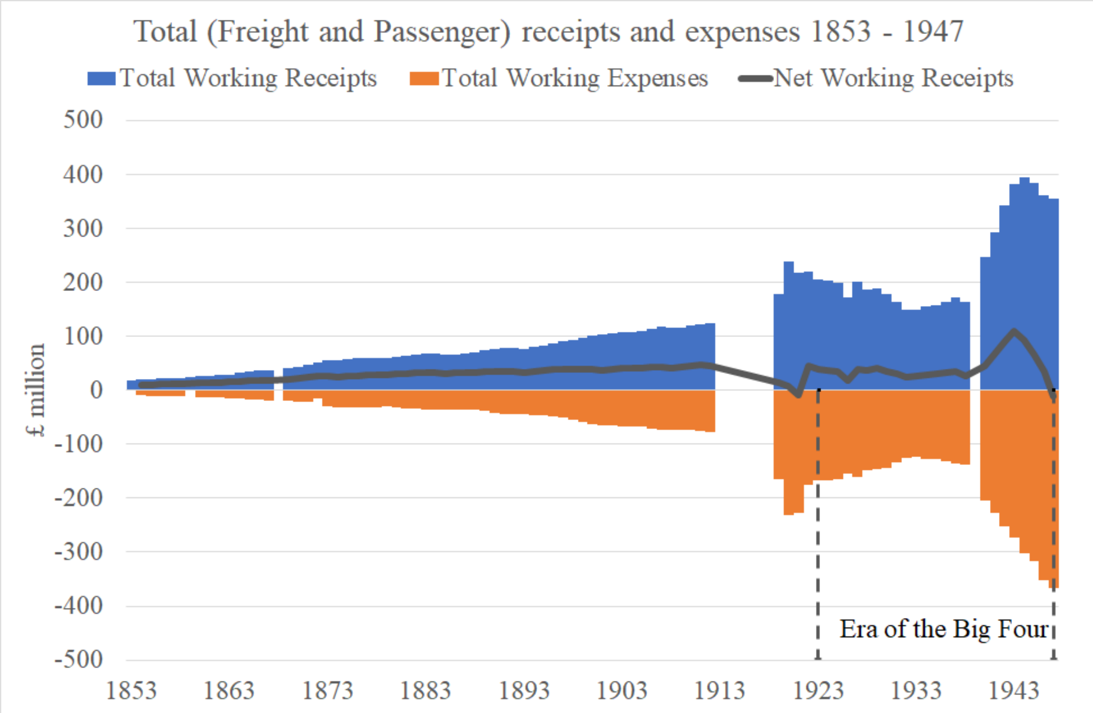


Figure 5.17 Total (Freight and Passenger) receipts, expenses and profitability 1853 – 1947.

Source: based on (Mitchell, 1988, pp. 545–550 (table 7)) and my analysis

World War Two undoubtedly played a major role in this financial outcome for the industry. Once again, railways were involved in war efforts. As happened prior to World War One, the Government appointed a Railway Executive Committee (REC) in 1938, consisting of the General Managers of the Big Four railways. The REC took control of the railways on 31 August 1939, supporting evacuation of people from cities, as well as the movement of troops and goods. The railways were to be "operated as a unified system" (Bonavia, 1980, p. 189), with the goal of reducing wasted mileage of freight and passenger traffic – **a different conception (loop 5, links and knots) of what the railways are for is in operation**. This is changing how railways and trains are configured and act.

Locomotive workshops were freed up for war efforts, with a reduced level of new stock built. Freight only travelled with full loads to avoid waste. Rationing of passenger journeys did not take place, but it was actively discouraged with a famous slogan 'Is Your Journey Really Necessary?' (Bonavia, 1980, p. 191) and an uncomfortable experience for those who chose to travel. Passenger accommodation was increased by abolishing First Class in the London area, and removing seat rests to permit four-a-side seating in Third Class.

When the War ended there was a need for investment in the railways. However, the railway organisations were never compensated by the Government for the reduced maintenance and lack of investment in railway assets during the war years. A need for investment was also happening at a point when the age of steam was beginning to reach its end, with diesel and electric power improving. Rail was also facing increasing challenges from roads and the growth of the private motor vehicle.

However, the era of the Big Four ended before the organisations were able to respond to these challenges. A General Election in July 1945 returned Clement Attlee's Labour Government to power, with a commitment to nationalise the railways. A new concept of the railways (loop 5, links and knots) saw them as **a single and unified railway as part of a wider transport system**. This concept of the railways as a part of wider integrated transport was arguably related to the perceived success of the London Passenger Transport Board, responsible for coordinating rail, bus, and tram across the capital.

The proposed changes to the railways, as part of a wider integrated transport system, were developed in a Transport Bill (His Majesty's Government, 1946) introduced on 28 November 1946, although there had been "virtually no contact between the civil servants engaged in drafting the Bill and the railways" (Bonavia, 1980, p. 199). The resulting 1947 Transport Act (His Majesty's Government, 1947, p. 146) identified 59 railway bodies, including the Big Four organisations, that were to be transferred to a newly created British Transport Commission (BTC). The period of rail nationalisation had begun.

5.3 Nationalisation and British Rail

The Transport Act of 1947 of Clement Attlee's post-war Labour Government fundamentally reorganised Britain's transport system, with a focus upon integration. The British Transport Commission (BTC) was accountable to the Ministry of Transport with responsibility to oversee railways, canals, and road freight transport. It was an enormous organisation, with an estimated 4% of the national labour force employed in BTC undertakings (Sloman, 1978, p. 33).

The Railway Executive was created from each of the four main railways and traded under the name *British Railways*. Although the Railway Executive was a part of the BTC, it was the Transport Minister who appointed members of the Railway

Executive (Bonavia, 1971, p. 43), probably because of its size and importance. The Railway Executive was estimated to employ 632,00 staff, with 20,000 steam locomotives, 1.2 million freight wagons, 56,000 coaches and 7,000 horses (Wolmar, 2007, p. 269). An early reorganisation moved some Big Four railway lines to the London Transport Executive (Johnson and Long, 1981, p. 29), and a diverse range of non-rail assets, including docks, hotels and canals, were moved to different Executives within the BTC.

The BTC left the Railway Executive to manage the railways, but reserved certain powers for itself (Johnson and Long, 1981, p. 63), including research and development and the annual building programme for locomotives and rolling stock. This structure appears to recognise the expertise of the railway organisations and their staff (loop 2, autonomization), but with centralisation of these reserved matters to support the new concept of the railways (loop 5, links and knots) as part of an integrated transport system.

The Railway Executive, within the BTC, was organised around six regional units: London Midland, Southern, Eastern, Western, North Eastern and Scottish. Implementation of national standards and practices met with resistance, because the new regional units were effectively formed from the Big Four. The Railway Executive had a difficult relationship with its regional units and with the BTC above it. The BTC considered that too much focus was given to internal railway questions of standardisation, and too little time looking at integration of rail with other transport modes and hubs. Two competing conceptions of the railways (loop 5, links and knots) were jostling for position. The BTC's concept saw the railways as part of a nation-wide integrated transport service, whereas the Railway Executive's concept focused upon integration of the previously separate rail networks into a single national rail network.

In 1947 the Railway Executive appointed Robert Riddles as the first Chief Mechanical Engineer of British Railways. Riddles saw nationalisation as an opportunity to achieve technical standardisation that had been "sought on British Railways since the 1860's" (Riddles, 1950, p. 678). Subsequently, the 1950s saw "a massive contribution to the unification of the railway systems of Britain" (Johnson and Long, 1981, p. 56). The first standardised designs of railway carriages began to be used c. 1954 (Robertson, 2005, p. 50), with Figure 5.18 below showing seats in

2+2 layout, with 3+2 also available for higher density services. The coaches were built with steel bodies, with the steel acting and contributing to a strong safety record during their service from 1951 to 1974.

Figure 5.18 Mk1 design visible in above photo with seating in 2+2 format

In a speech at the Institute of Mechanical Engineers (loop 2, autonomization) in 1950, Riddles stated “there is a case for continuing the development of the steam engine along with the diesels and electrics for some time yet” (Riddles, 1950, p. 681). This recognised the different attributes of trains powered by steam, diesel and electric, with steam often able to offer the most economical option given the industry knowledge (loop 2, autonomization) of this technology and its long history of development. On this basis Riddles continued to order steam locomotives on a large scale from 1948 to 1953 and also introduced “a series of new and efficient steam locomotives utilising interchangeable and standardised parts” (Holland, 2015, p.

227). However, this Indian Summer (Bonavia, 1980, p. 97) for steam would prove illusory.

In the 1951 General Election, Winston Churchill's Conservative Party came to power again. The new government viewed the 1947 Act, which created the BTC, Railway Executive and nationalised the Big Four, as an "abhorrent symbol of the triumph of public planning over private enterprise….[that] destroyed the individualism and boldness of the former Companies" (Johnson and Long, 1981, p. 58). The concept of the railways as part of a centrally controlled and integrated transport system was rejected (loop 5, links and knots).

The Government published a White Paper in May 1952, criticising the BTC and stating that "even if integration in the fullest sense were practicable, it would result in a huge unwieldy machine" (Her Majesty's Government, 1952, p. 2) ill-suited to the demands of modern industry and life. The resulting Transport Act of 1953 (Her Majesty's Government, 1953) allowed the railways more commercial freedom to adjust their pricing, and focused upon competition and decentralisation (loop 5, links and knots). The British Transport Commission survived for the moment, but the Railway Executive was abolished from 1 October 1953 and replaced by six Area Boards with responsibility for the railways in different parts of Britain. The Area Boards reported into the BTC, which retained control of certain *reserved subjects*, including standards for the design, manufacture, and maintenance of locomotives, carriages, and wagons.

Recognising that investment had been missing from the railways since the War, the BTC was given significant investment as part of a Modernisation Plan (British Transport Commission, 1954). The Plan began in 1955 and, over 10-15 years, was intended to address the financial deficit and bring the railways up to modern standards. Investments included a large sum of £1.2 billion (£33 billion at 2019 prices) to be spent upgrading track and signalling (£210m), replacing and improving passenger coach stock, improving stations (£285m), and modernising freight services and yards (£365m). Also included was £345m (£9.2 Bn at 2019 prices) so that steam was "replaced as a form of motive power" (British Transport Commission, 1954, p. 6) with a stated desire to introduce electric or diesel traction quickly. The Modernisation Plan was acting to change the configuration of trains. This would mean the end of BR's 19,000 steam locomotives. This included 12 new classes of steam locomotive developed by Riddles in 1954 that reflected "the epitome of British steam locomotive design…but survived less than a decade" (Holland, 2015, p. 227), with some lasting only five years, despite a planned working life of 40 years. The earlier Big Four, with an emphasis upon technical leadership embodied in their famous engineers (loop 2, autonomization) had been replaced. A concept of railway modernisation had reconfigured the railways (loop 5, links and knots). With a lot of investment money behind it steam motive power was removed from the actor-network of a train, apparently despite the analysis of the CME, who believed it could still play a role for some time (Riddles, 1950, p. 681).

Although diesels were more expensive than their steam predecessors, they did have advantages. Diesels were cleaner, had lower maintenance and running costs, and had a larger operating range. However, the Modernisation Plan failed to take into account the "almost complete lack of expertise in building diesel locomotives in Britain" (Holland, 2015, p. 230) (loop 2, autonomization). For example, the North British Locomotive Company was founded in 1903 in Glasgow and became the largest locomotive manufacturer in Europe. However, "when it moved from steam to diesel production in the late 1950s…it went on to build some of the most unreliable locomotives ever ordered by BR" (Holland, 2015, p. 158). Despite the lack of industry capability, the British Transport Commission "hurriedly ordered nearly 3,000 mainline diesel locomotives of various non-standard types even before prototype testing had been properly evaluated" (Holland, 2015, p. 234).

By 1960 the earlier hope of the 1955 Modernisation Plan was replaced by a negative outlook. In response to a record industry loss of £67m, and the perceived failings of the Modernisation Plan, the Government calling for *sweeping changes* because of the *grave financial plight* facing the railways (Her Majesty's Government, 1960). The British Transport Commission was viewed as too large and diverse to be managed as a single undertaking, with British Railways dominating activities owing to its size and complexity. The Government's White Paper also noted frequent confusion within the BTC "judging between what is economically right and what is socially desirable" (Her Majesty's Government, 1960, p. 4). A new concept of the railways (loop 5, links and knots) was developing. This new concept recognised a tension highlighted earlier in this chapter by the fish trader in Berwick c. 1890, who wanted their goods to be carried and did not care if the railways recovered their costs (loop

5, links and knots). We can see here a concept of the railways as a utility and social necessity that is jostling with other conceptions of the railway as an industry that covers its own costs.

The resulting Transport Act (Her Majesty's Government, 1962) dissolved the British Transport Commission. Separate Boards were created for parts of the BTC, including British Railways, London Transport, British Transport Docks, Inland Waterways, and others. The newly created British Railways Board reported to the Transport Minister and managed six Regional Railway Boards – Eastern, London Midland, North Eastern, Scottish, Southern, and Western. Matters reserved for the British Railways Board included the "design, procurement, allocation and overall control of rolling stock and ships" (Bonavia, 1971, p. 98), as well as pay negotiations, finance and investment. The Act stated that none of the Regional Railway Boards were to be "regarded as common carriers" (Her Majesty's Government, 1962, p. 45), thereby finally removing a requirement that had existed for rail since the 19th century.

The Minister of Transport at the time was Ernest Marples MP, who had a background with a successful road construction company. In 1963, the Minister appointed Dr Richard Beeching as the first Chairman of the new British Railways Board. A different commercial concept of the railways (loop 5, links and knots) emerged under his leadership. This was described in *The Reshaping of British Railways* (British Railways Board, 1963), more commonly known as the Beeching report.

This different concept of the railways (loop 5, links and knots) was based around its "specialised and exclusive route system" (British Railways Board, 1963, p. 57). , which was efficient for dense flows of well-loaded trains. This meant that many lesser used lines and stations, which did not fit this concept, were to be closed. They did not fit the new concept (loop 5, links and knots) and so they were effectively no longer railways, despite their track, stations, signals and more. The report recommended the closure of more than 2,300 stations (one third of the total at the time) and 6,000 miles of route. This resulted in the loss of approximately 70,000 jobs in British Railways over several years. The changes had a drastic impact, as can be seen in Figure 5.19 below, which shows the first descriptive statistic used in this chapter – the length of the physical railway. The chart updates the values to the present day.

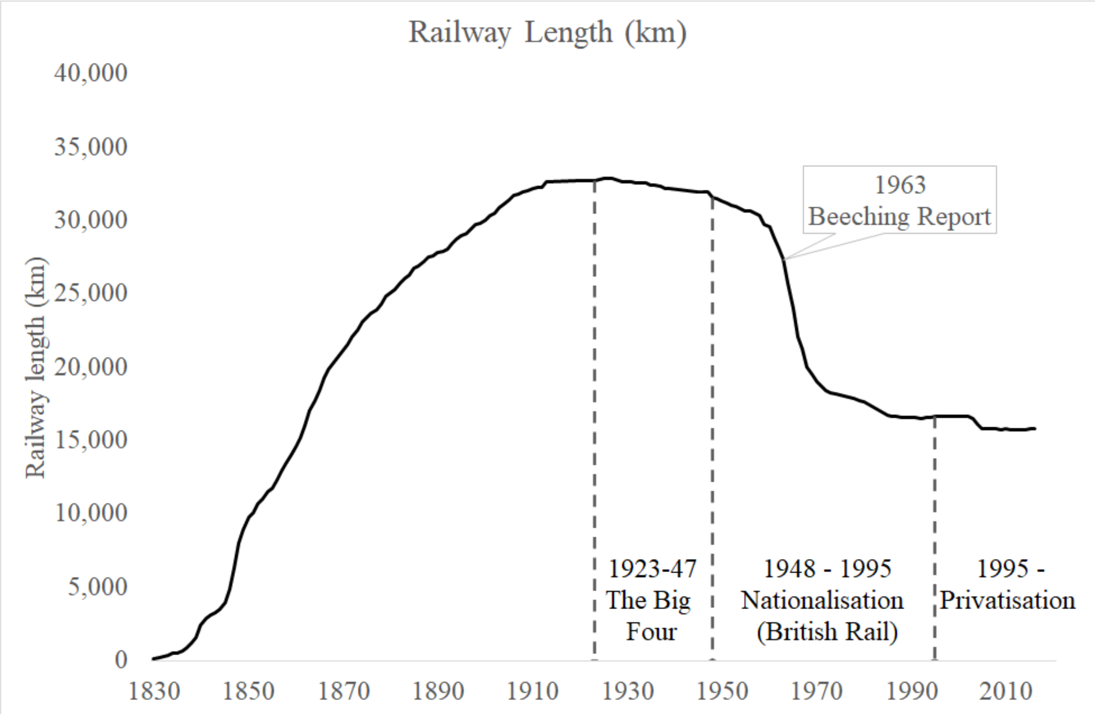


Figure 5.19 Historical growth of the railway in Britain – the length of the railway (1830-2016)

Source: based on (Mitchell, 1988, pp. 541–542 (table 5); Office of Rail Regulation, 2017 Table 2.52) and my analysis

The extent of railway infrastructure had already reduced before 1963, however the effect of the Beeching Report and its new concept of the railways was drastic. By 1970 the railway was approximately 19,000 km – the size of the network in the year 1866 during railway mania. Further small reductions continued after this period, but never to the same degree, with the figure for 2016 showing the UK network as 15,811km, similar in size to the network in 1862.

A key objective of the Beeching reports was to address the £67M loss made by the railways in 1960. Some of the smaller lines were undoubtedly unprofitable, but cost savings made minimal impact, even if there were a lot of them. By 1970 the railway was still making a loss, although this had reduced to £22M, as shown by the black line in Figure 5.20 below.

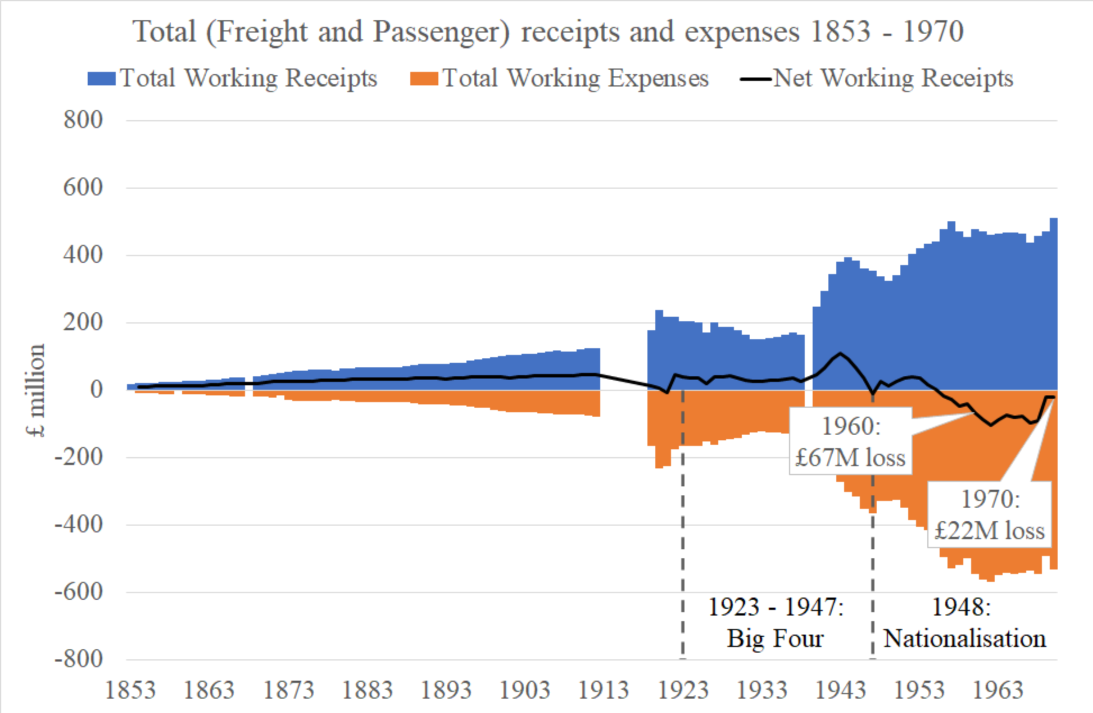


Figure 5.20 Total (Freight and Passenger) Working Receipts, Expenses and Net Working Receipts 1853-1970

Source: based on (Mitchell, 1988, pp. 545–550 (table 7)) and my analysis

Dr Beeching delivered a follow-up report (British Railways Board, 1965) focused upon the central trunk routes, that identified 3,000 miles (4,800 km) of the 7,500 mile (12,100 km) trunk railway for investment. This second report regretted that the public focus had been upon the *abandonment of the unsound parts of our railway system* and sought to draw attention to the “constructive proposals for the development of a new railway out of the old one” (British Railways Board, 1965, p. 5). However, it is not possible to say if these additional changes would have been successful, because Harold Wilson’s Labour Government came to power in 1964. Dr Beeching’s proposals were rejected, and his time as the first Chair of the British Railways Board finished in 1965.

The new Minister for Transport, Barbara Castle, formed a Steering Group, set up with staff from government and the British Railways Board – bringing together industry expertise (loop 2, autonomization) and Government (loop 3, alliances) as often happened in the early days of the railway, although Government was more actively involved now. The subsequent report recognised that, although some railway services had little chance of paying their way economically, their “value to the community outweighs their accounting cost” (Ministry of Transport, 1967, p. 1). The social and economic benefits to the country of a substantial railway system were recognised and a new concept of the railway was developing (loop 5, links and knots).

The resulting Transport Act (Her Majesty's Government, 1968) introduced the "recognition in statute of the separate **social and commercial roles of the railway** [emphasis added]" (Johnson and Long, 1981, p. 78). The Minister was to take responsibility for approving specific grants to support "unremunerative passenger services" (Her Majesty's Government, 1968, p. 58), in light of the social and economic benefits of those services. British Rail became the first of the nationalised industries to have "its social obligations identified and priced separately" (Gourvish and Anson, 2002, p. 50), with grants approved by the Minister. The Act also sought to bring back some of the previous Labour Government's desire for rail and bus integration, albeit at a local level, rather than managed nationally. Passenger Transport Authorities were created, initially for Merseyside, West Midlands, Tyneside, and Greater Manchester, to provide more localised decision-making. The 1968 Transport Act also saw a need for further reductions across the network, with cuts identified to take it from 13,200 miles (21,243 km) to 11,000 miles (17,703 km), but the drastic reductions of previous times were stopped. By 1968, some 20 years since nationalisation, staff numbers had "dropped from over 640,000 to 296,000 and 20,000 steam locomotives had been replaced by diesel or electric traction" (Johnson and Long, 1981, p. 79), with similar scale of reductions at freight terminals, yards, and stations. A lot of change in the configuration of railways, but more was to come.

The 1970 General Election returned a Conservative Government under Edward Heath. During this period, the UK joined the European Community and a global oil and energy crisis occurred. The Labour government of Harold Wilson took power from 1974, with industrial relations becoming a critical issue, and railway unions playing a full part in "labour assertiveness" (Gourvish and Anson, 2002, p. 6). The Labour Government introduced the Railways Act of 1974 (Her Majesty's Government, 1974), which included, among other measures, a "block grant system covering the passenger network as a whole" (Gourvish and Anson, 2002, p. 12). Instead of specific grants to support specific unremunerative services, this approach was replaced by a block grant provided to cover BR's continued losses. This block grant, known as the Public Service Obligation (PSO), reflected a concept of the railways as a whole network, including specific services that needed economic support (loop 5, links and knots).

The relationship between Government and the nationalised industries was fraught. A lack of trust existed between the railways and Government (loop 3, alliances) (National Economic Development Office, 1976, p. 8), with the perception of a perpetual audit process (Gourvish and Anson, 2002, p. 44). The role of the railways in Government Transport Policy remained unclear, with no system for reaching agreement on long term objectives and strategy, and no effective system for measuring performance. The 1968 and 1974 Railway Acts may have recognised the social and economic value of the railways, but a report by the British Railways Board found "little account of social and environmental factors" (1976, p. 10) in decision-making, apart from vague requests to "'help energy conservation', 'get traffic off the roads' or 'help preserve the environment'" (British Railways Board, 1976, p. 23).

A Government White Paper (Her Majesty's Government, 1978, p. 10) recognised the need for clarification of the responsibilities of Government and the railways. However, by 1980 the industry was £677M in the red (Figure 5.21 below), with expenses having grown significantly faster than income.

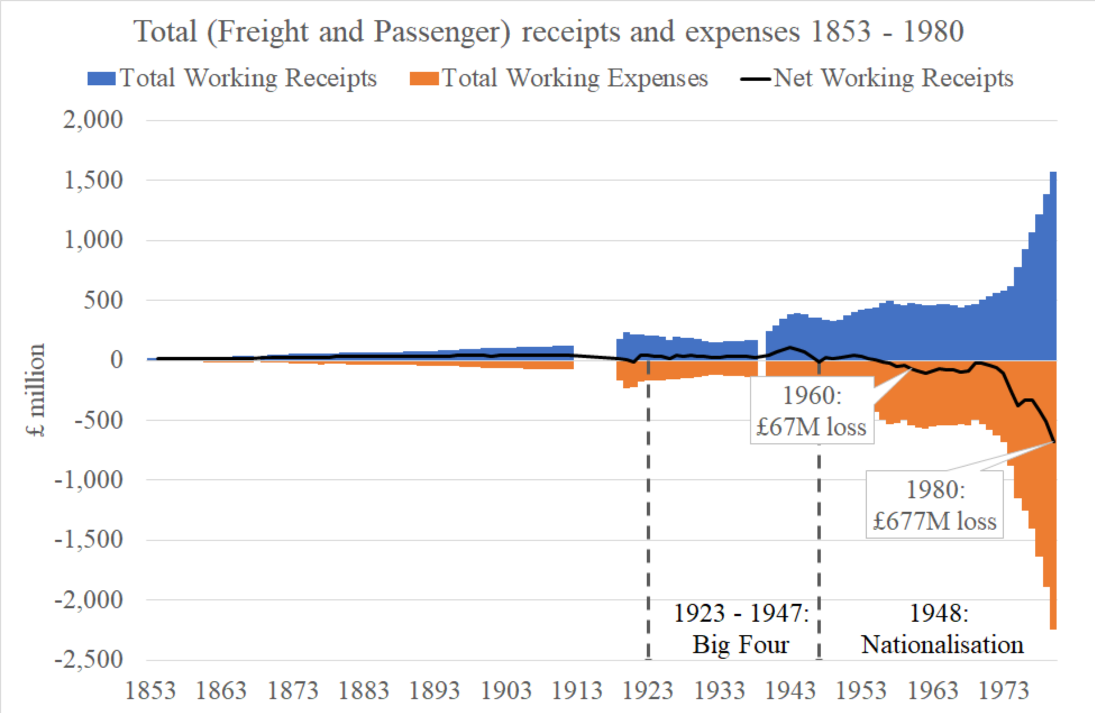


Figure 5.21 Total (Freight and Passenger) Working Receipts, Expenses and Net Working Receipts 1853-1980

Source: based on (Mitchell, 1988, pp. 545–550 (table 7)) and my own analysis

The 1980s would be the decade of privatisations – telecommunications (1984), gas (1986), water (1989), and electricity (1990) – and British Rail would not be immune. The Conservative Government of Margaret Thatcher was elected in the 1979 General Election with a focus upon reducing the size of the public sector and growing *free enterprise*. The British Railways Board (BRB) "wanted privatisation to involve the attraction of private capital" (Gourvish and Anson, 2002, p. 232), with the public sector gaining capital for investment, but retaining an ownership stake. The Government's main desire was to reduce spending and the size of the public sector.

A railway privatisation process began that would span the next two decades. First was the sale of subsidiaries outside core railway activities. Between 1980 and 1990 assets were sold that generated £1.4Bn income for British Rail (Gourvish and Anson, 2002, p. 254), with the bulk (£1.2Bn) coming from the sale of non-operational BR property and land. Also included in the sale were various activities that had accrued to the railways over time, such as British Transport Hotels, BR Hovercraft, Superbreak holidays, Hoverspeed UK, Sealink, British Transport Advertising and Travellers Fare. A claim was made that that these businesses were "languishing in a public sector industry” (Gourvish and Anson, 2002, p. 253) dominated by the core activity of railways.

Competitive tendering for the railways’ rolling stock requirements began in 1983. Over the following four years (Gourvish and Anson, 2002, p. 243) the private sector obtained orders of £380M out of a total of £720M for passenger vehicles, and £45M out of £100M for freight vehicles. Another precedent was set within freight when Foster Yeoman, a large quarrying business, introduced its own diesel locomotives from General Motors in 1986. By 1987/8 31% of the railway freight wagon fleet was privately owned, and a year later the proportion was close to 50%, producing “privatisation in essence, even if no transfer of ownership was involved” (Gourvish and Anson, 2002, p. 243).

British Rail Engineering Limited (BREL) designed and built rolling stock for BR, however, a government report noted that British Rail was “the only major railway in the world, other than that in India, which manufactures its own stock” (Department for Transport, 1982, p. 37). In October 1987 the end came to 140 years (Gourvish and Anson, 2002, p. 245) of British Railways building the rolling stock that they also operated. By 1989 BREL was sold to a consortium involving former management and large engineering organisations. It would eventually become part of Bombardier Transportation.

On 12 December 1988 problems with the railways were brought to the fore, when a major crash at Clapham Junction killed 35, and injured 484. BR accepted the blame, which was “the result of faulty wiring in an electrical box following poor maintenance by a signalling engineer” (Wolmar, 2007, p. 297). Safety concerns featured prominently in the national press (loop 4, public representation). The purpose of the railways and how they should be organised was up for national debate (loop 5, links and knots). British Rail was viewed as too large, especially when compared to perceptions of an earlier *golden age* of railways.

The options considered for privatisation were “selling BR as a whole (unitary); selling by business sector; selling by region; and separating BR into track and operating companies” (Gourvish and Anson, 2002, p. 384). An influence upon this process came from a European Union (EU) directive (91/440/EC) that recognised “greater integration of the Community transport sector is an essential element of the internal market" (European Union, 1991, p. 1). This concept of the railways saw them as part of an integrated transport system to support the European Community (loop 5, links and knots). The EU directive required separate accounting of rail infrastructure and rail services (Gourvish and Anson, 2002, p. 262), but this could be an administrative and reporting exercise, and did not necessarily mean separate ownership and organisational structures.

On 9 April 1992, a General Election saw an unexpected win for the Conservative party, led by John Major, who had promised to "end British Rail's monopoly…and restore the pride and local commitment that died with nationalisation" (Conservative Party, 1992, pp. 14 & 44). The latest era of the railways was beginning with privatisation of the core railway services. The actor-network of resources that act as a railway was still recognisable when compared even with the Liverpool & Manchester Railway of 1830, but the concept of the railways (loop 5, links and knots) holding this diverse collection of resources together was about to go through a change that had never been seen to this extent – the separation of wheel and rail.

A privatised industry structure was about to separate the ownership and management of the track and other infrastructure, from the ownership and operation of the trains and railway services that operate on the infrastructure. This structure would still act as a railway, but with a radical reconfiguration of resources and relationships.

5.4 Privatisation

As the details of privatisation were finalised, British Rail managers had a "strong preference for vertically integrated franchises" (Gourvish and Anson, 2002, p. 394), with track and trains under the control of the same organisation for an area or sector – a geographically integrated concept of the railways (loop 5, links and knots) similar to the Big Four era. Vertical integration appeared to be an essential feature of railways across the world (Wellings, 2014, p. 257), whether they had developed in the public or private sector. Japanese National Railways was privatised in 1987 and had maintained vertical integration, with a breakup into six regional passenger companies, and one freight company.

The alternative to vertical integration was to separate ownership of the infrastructure, from the operations that run on that infrastructure. Sweden had chosen this approach in 1988, but the two companies that were created remained publicly controlled with minimal on-rail competition. Vertical separation of infrastructure and operations had been applied in other UK privatisations (gas, telecommunications, water) “on the grounds that the grid or infrastructure was a natural monopoly” (Wellings, 2014, p. 257). The national electricity grid, for example, could be managed as a separate whole, whereas the operations using that infrastructure could be more easily broken up. In making the decision, it was said that the Prime Minister, John Major, was also “influenced by the fact that the safest transport industry in the country was also the most fragmented: namely Civil Aviation” (Wolmar, 2017, p. 69). A new concept of the railways (loop 5, links and knots) was apparently being informed by a *chain of translation* (Latour, 1999, p. 92), creating equivalence, to some degree, between trains and planes, trains and water, and trains and gas. Vertical separation was to be implemented in the UK, with private sector organisations operating franchised services for different routes and geographies, and a rail infrastructure manager, Railtrack, that was initially within the public sector. During the 19th and early 20th century a train from one operator would sometimes run on the infrastructure of another organisation, but, as a permanent way of organising the railways, this had never been seen before.

In July 1992 a Government White Paper (Department for Transport, 1992) set out how British Rail was to be privatised and broken into its component parts, with contractual agreements to manage the resulting commercial and operating relationships. A Bill was “drafted and passed while policy was still evolving” (Welsby and Nichols, 1999, p. 61). The Railways Act of 1993 (Her Majesty’s Government, 1993) led to the restructuring of BR “into 90 to 100 companies” (Welsby and Nichols, 1999, p. 61) in preparation for subsequent privatisation. I will describe this new concept of the railway (loop 5, links and knots) as *functional specialism with contractual and regulatory integration*.

A nationalised infrastructure provider, Railtrack, was responsible for managing the track, stations, and other parts of the railway network. A newly created Regulator was to monitor Railtrack’s costs and outputs, using various metrics to measure the state of bridges, the renewal of track, and more (loop 1, mobilisation of the world). However, regulation would still face the “perennial problems…of reconciling public service objectives, particularly for passengers, with commercial ones” (Gourvish and Anson, 2002, p. 422).

BR's train operations were moved into the private sector in the form of 25 passenger franchises, or train operating companies (TOCs), and three freight operating companies (FOCs). The franchisee would own few assets – leasing rolling stock from rolling stock leasing companies (ROSCOs) and paying charges to operate on Railtrack infrastructure. In 1995 the first two passenger franchises were awarded and, by March 1997, all 25 had been let. A Franchising Authority (the Office of Passenger Rail Franchising) would oversee the franchise process and monitor franchisees.

Three rolling stock leasing companies (ROSCOs) would own the bulk of BR's rolling stock and lease it to TOCs. The need for ROSCOs was driven by the Government's initial desire for short-term rail operating franchises of 5-7 years, whereas rolling stock has a life of 25-40 years. The ROSCOs were there to provide longer-term asset management of the trains, and to reduce the capital investment requirements for operating franchise bidders, who only had to meet the annual leasing requirements. In April 1993 the Government announced that British Rail's "entire fleet of 11,000 vehicles" (Gourvish and Anson, 2002, p. 420) was to be transferred to three newly created ROSCOs – Angel Trains, Eversholt Leasing, and Porterbrook Leasing.

By 1994 it was decided that Railtrack would also be privatised, and it was listed on the London Stock exchange in May 1996. The Government had a "desire to complete the privatisation prior to the 1997 General Election" (Butcher, 2010, p. 14).

The General Election of May 1997 saw the victory of Tony Blair's Labour Party. Labour talked about *integrated* transport, although "what exactly 'integration' meant was never really made clear" (Docherty, 2003, p. 13). Alternatives to the privatised industry structure were investigated, but radical change would involve large sums of government money, at a time when the Chancellor, Gordon Brown, was seeking to demonstrate prudence. Simplification was a recurring theme from commentators outside of Government (Shaw and Farrington, 2003, p. 128), with Labour encouraged to reduce the number of franchises, reduce maintenance complexity, and more.

On 19 September 1997, the new government was compelled to focus more upon the railways, when a Great Western InterCity-125 passenger service failed to stop at a red signal and hit an EWS freight train at Southall in West London, killing seven passengers and injuring 139. Driver error and failed onboard train control systems (both part of the collection of resources that acts as a train) brought safety concerns to the fore of public attention (loop 4, public representation). In response, the Government established a "Strategic Rail Authority (SRA) for Great Britain, to provide a clear, coherent and strategic programme for the development of our railways" (Department for Transport, Local Government and Regions, 1998, p. 37). Before the SRA was legally established, another serious accident happened at Ladbroke Grove in West London on 5 October 1999. A Thames Train passed a red signal and crashed into a First Great Western High Speed Train, with 31 people killed. The prime cause was identified as human error but it "raised general issues relating to the governance of the privatised railway" (Gourvish, 2008, p. 55). Before the repercussions could be fully understood this accident was unfortunately followed by another. On 17 October 2000 at Hatfield on the East Coast mainline north of London, a broken rail caused a GNER train to derail, when travelling from King's Cross to Leeds – killing four passengers and injuring 70 more. Responsibility was attributed to Railtrack and its maintenance contractor, Balfour Beatty Maintenance. Railtrack's response saw the railway nearly shut down, with speed limits and line closures imposed across the network and an "expensive maintenance binge" (Gourvish, 2008, p. 73). In the privatised concept of the railway (loop 5, links and knots) different organisations are responsible for various parts of the action. In this case, responsibility for the failure has been directed to Railtrack and Balfour Beatty, although proponents for a nationalised railway pointed at the privatised structure itself (loop 5, links and knots).

As part of the response to this failure, the Strategic Rail Authority (SRA) was given legal status by the Transport Act 2000 (Her Majesty's Government, 2000), effective from 1 February 2001. The Franchising Regulator, OPRAF, was abolished by the same Act and its responsibilities given to the SRA. On 7 June 2001, a General Election returned a Labour government for a second term. Railtrack lobbied the Regulator and Government for additional funds for maintenance and renewals work. The Government was not willing to provide additional financial support to Railtrack and so Stephen Byers, the new Secretary of State for Transport, Local Government, and the Regions, placed Railtrack into railway administration on 7 October 2001. A new company, Network Rail (NR), was created to buy Railtrack plc on 3 October 2002.

Network Rail stated that it would require more than £6 billion per year funding – almost double the provision agreed by the earlier regulatory review of 2000 – but this posed a threat to public expenditure levels. In response, a Government White Paper (Department for Transport, 2004) and subsequent Railways Act (Her Majesty's Government, 2005) implemented further changes to the control and management of the railways. Safety regulation moved from the Health and Safety Executive to the Office of Rail Regulation. The Strategic Rail Authority was to be closed, with Network Rail given a leadership role for the industry.

The SRA was gone, but during its brief time (c. 2000 – 2006) it had brought a central "directing mind" (Gourvish, 2008, p. 280) to the railway. Its legacy was visible in a new funding process, whereby government was required to define more explicitly what it expected from rail in return for the funds made available. This clarification of Government's expectations reflects the concept of the railways (loop 5, links and knots) and effectively asks "what are the railways for?" (Shaw and Farrington, 2003, p. 130).

Further changes in the configuration of resources that act as a railway occurred when, in October 2003, Network Rail was approved to bring infrastructure maintenance back in-house, based upon a view that this failure was a key contributor to accidents. From 2014 Network Rail was "reclassified from the private sector to the central government sector in the UK national accounts" (Office of Rail and Road, 2017, p. 45). Network Rail is an arms-length body of the Department for Transport (DfT) and recognised in government debt finances.

The descriptive statistics used throughout this chapter provide insight into the current railway compared to earlier times. Figure 5.22 below shows the number of passenger journeys on the railway. In 2018, a record 1.76 billion passenger journeys were made – the highest level of usage ever in the history of the railways.

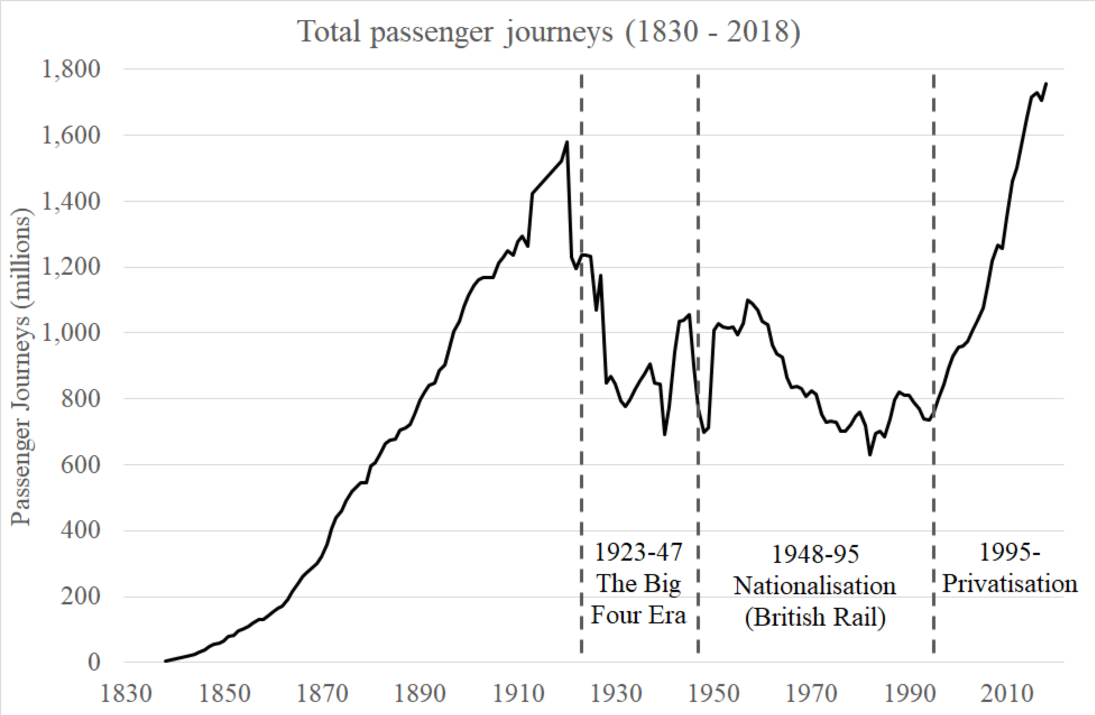


Figure 5.22 Historical growth of Rail Passenger Journeys in Britain (1830-2018)

Source: based on (Mitchell, 1988, pp. 545–550 (table 7)), Office of Rail and Road (ORR) Table 12.5 (Passenger journeys by year) and my analysis

However, this increase in passenger usage has been achieved with higher levels of government support than was provided during the days of British Rail, as shown in Figure 5.23 below.

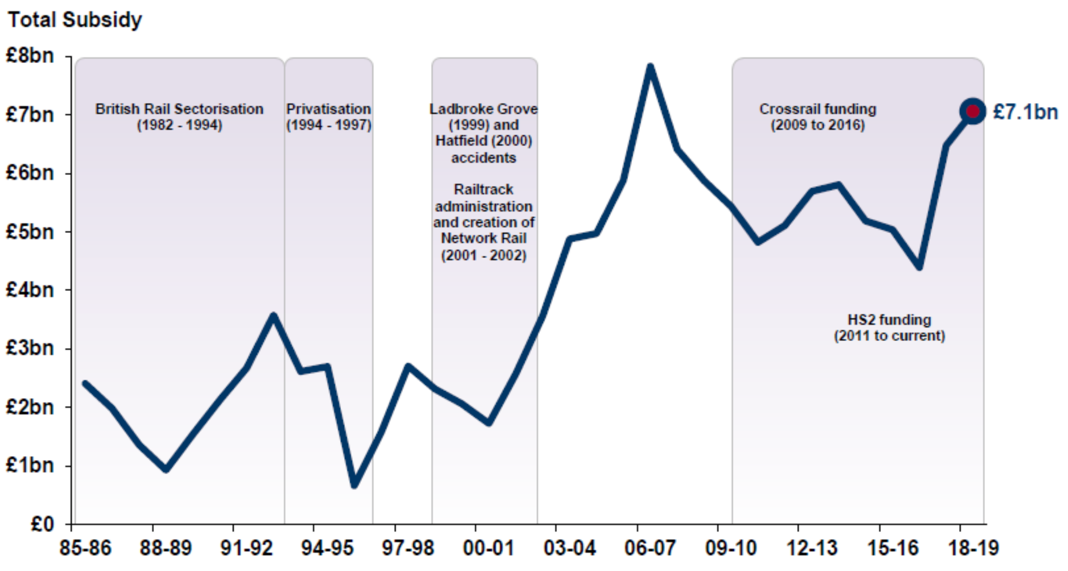


Figure 5.23 Government support to the rail industry in real terms, Great Britain, 1985-86 to 2018-19

Source: Rail Finance 2018-19 Annual Statistical Release (Office of Rail and Road, 2019a)

It was not possible to obtain data to update the descriptive statistic for railway income, expenses, and profits. However, Figure 5.23 above shows government support to the rail industry since 1985. The spike in government support is clear after the accidents that led to the demise of Railtrack and the introduction of Network Rail. In 2018-19, total subsidy to the industry was £7.1 bn. By comparison, Government support to the railway in 1994-95, during the last days of British Rail, was £1.5Bn (Parliament. House of Commons Papers, 1995, p. ix Table 1), which is equal to £3.0bn at 2019 prices. In 2019 the privatised railway received more subsidy than the former nationalised railway under BR.

The record usage of the railway by passengers, shown above in Figure 5.22, has taken place on a smaller network than the previous record number of passenger journeys, achieved in 1920. The rail network today is approximately 15,800 km in track length, whereas in 1927 it reached a maximum of 32,850 km, as shown in previous charts (Figure 5.5, Figure 5.11, and Figure 5.19). The implications of record usage and a reduced network can be explored by combining the descriptive statistics for passenger journeys and length of the network together. Figure 5.24 below shows the resulting number of passenger journey per track km.

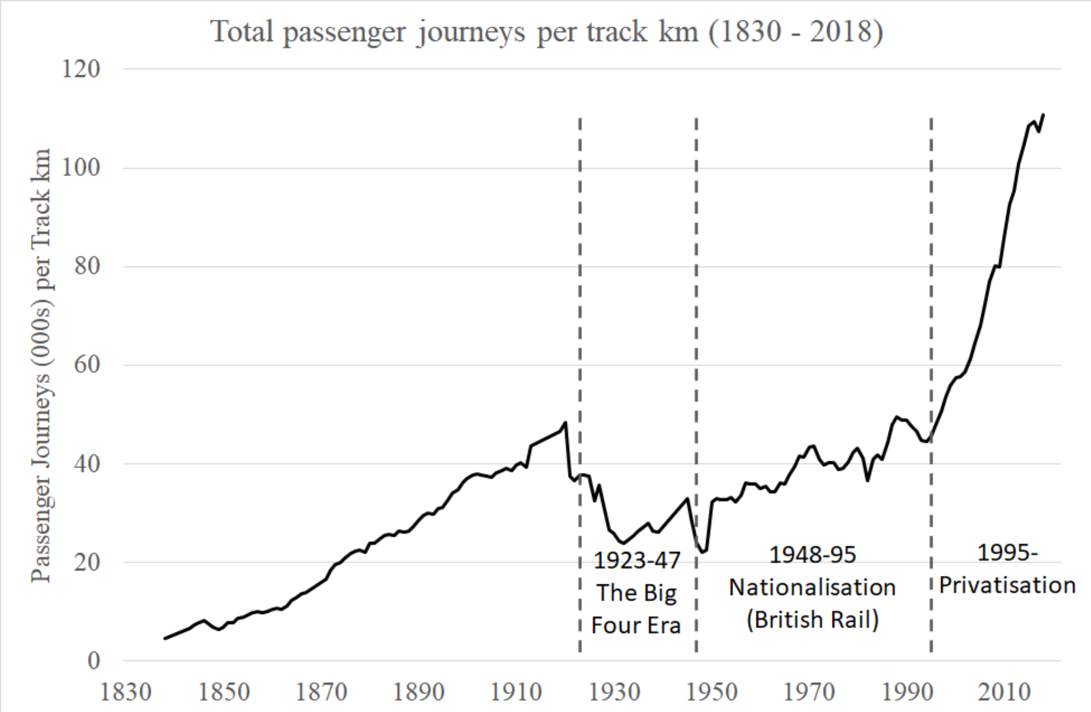


Figure 5.24 Historical Passenger Journeys per track km (1830-2018)

Source: based on (Mitchell, 1988, pp. 541–542, 545–550 (table 5, table 7)), Office of Rail and Road (ORR) Table 12.5 (Passenger journeys by year); Office of Rail Regulation, 2017 Table 2.52) and my analysis

Figure 5.24 above shows that the era of privatisation is associated with a much greater intensity of use of the railway, as measured by the record number of passenger journeys taking place on the same extent of physical network. Capacity and crowding are significant issues for the modern railway, but they are not the only ones.

In 2018 the Conservative Government commissioned the Williams Rail Review to look at the structure of the whole rail industry and the way passenger rail services are delivered. At the time there was increasing public support for re-nationalisation, although some argue that the current privatised railway has “even greater state control than at any time since the days of the British Transport Commission following nationalisation in 1948” (*Modern Railways*, 2017, p. 6). Network Rail and DfT are dominant actors in the industry, and both are public sector organisations. The new CEO of Network Rail, Andrew Haines, appointed in August 2018 has significant experience of the operational side of the railway (loop 2, autonomization) and has called for a more joined-up industry (loop 5, links and knots), with integrated performance targets (loop 1, mobilisation of the world) for Network Rail and the Operators.

The COVID-19 pandemic of 2020 impacted the railways significantly and has led to even greater government intervention and control. The future structure of the rail industry is expected to undergo further changes.

5.5 Summary of the historical analysis of the railways

When viewed through the lens of Actor-Network Theory the railways bring together a variety of resources, including trains, that *collectively act*. The five-loop model (Figure 5.1) encourages a broad view of action, with resources drawn from within the railway industry and beyond. Holding this collection of resources together is a concept of the railway (loop 5, links and knots) that has changed over time. This concept of what the railway is, and what it is for, will influence the type of trains produced.

The earliest concept was characterised as **a multiplicity of local railways**, reflecting the individual and bespoke nature of these hyper-local railways tightly coupled with their specific circumstances and geographies. For example, a railway in a hilly area may act using gravity, horses, or people to provide motive power.

As the railway matured, a new concept of **mass transit** began to develop. Gladstone's Act of 1844 required the provision of certain levels of service for third class passengers. Early begrudging responses by railway organisations were given impetus in 1872 when the Midland Railway went above and beyond what was required, and third-class railway income became increasingly important.

The increasing success and importance of the railways led to new conceptions towards the end of the 19th Century. The railways had become integral to so many other social activities that access became a necessity – effectively the railways had become **an essential service for many** and not a discretionary one. This was most clearly articulated by the fish trader in Berwick who wanted his fish to be carried but did not care whether this was economical for the railways.

During World War One the concept of the railways was based upon support for the war effort. Resources cannot be wasted, service is reduced to a bare minimum, and the railway is focused upon **maximising the efficient movement of goods and people**.

After World War One, recovery is important and efficiency efforts focus upon consolidation of the industry and standardisation of practices within each of the Big Four. However, this consolidation also introduces a rivalry and competition for technical leadership, most clearly visible in the quest for speed. This concept could be described as **consolidation and optimisation**, with the Big Four and their Chief Mechanical Engineers demonstrating their ability to optimise the performance of steam locomotives, as the end of the steam age approaches.

World War Two sees a return to the railways run in support of the war effort. The post-war period introduces a new concept of the railways as a part of a **nationally integrated transport system**. However, there was a tension between this multi-modal view of integrated transport and the newly nationalised railway's concept, which focused upon the creation of a **national rail network** that unified the previously separate Big Four railways.

A new government came to power with a perception that the earlier boldness of the railways was lost within the British Transport Commission and its desire for centrally managed transport integration. The new concept that developed could be described as **local empowerment within a nationalised railway**. The railways remained in public control, but they were removed from the requirement for integrated transport, as embodied in the British Transport Commission. The British Railways Board managed six Area Boards with responsibility for the railways across the regions.

Significant investment, in the form of the Modernisation Plan, was provided reinvigorate the railways. Robert Riddles, the CME of BR, had intended for steam locomotives to continue to play an active role in the railways, but the Modernisation Plan effectively acted to remove steam power from the resources that act as a train within the railways. The concept of the railways at this time could be described as **centralised funding and technological decision-making,** to reflect the provision of significant funds, but with decisions regarding how those funds should be spent, apparently, centrally directed towards diesel and electric.

Problems with new diesel engines contributed to perceived failings of the Modernisation Plan and alternative conceptions of the railways developed. The Beeching era saw the railways as a **transport provider of specialist infrastructure**, with a focus upon core routes where this costly specialised infrastructure was of most use compared to other transport alternatives. Parts of the railway that did not fit this concept were closed and no longer act as railways, as the network is drastically reduced.

Probably as a reaction to this, a new concept of the railway developed after the Beeching cuts. This recognised the importance of **the social railway**, which brought additional benefits that could be lost with a narrow economic view. The Government provided economic support for the railway's uneconomic services that provided social benefits.

The era of privatisation in Britain introduced competing concepts driven by the privatisation of other nationalised industries in water, gas and telecoms, and aviation. Privatisation meant that BR was to be "vertically separated" (Shaw and Farrington, 2003, p. 110) with specialist organisations responsible for components of the previously vertically integrated activities. This new concept could be described as **functional specialisation with contractual integration**.

The next chapter investigates recent strategic decisions that have produced lightweight trains for the Thameslink and Crossrail railways. These strategic decisions are taking place within a concept of the railways that could arguably be slightly modified from its predecessor. I will describe the current concept of the railway as **industry-led integration within the functionally specialised and contractual railway.** This is admittedly a bit of a mouthful! This new concept is still influenced by the industry structure, with its vertical disaggregation and specialisation – separation of wheel and rail – but there is a noticeable desire for *more integration and joining up* within the railway. The public sector infrastructure owner, Network Rail, is a dominant organisation now led by a CEO who has spent many years in the operational side of the industry. Contractual incentives continue to act and influence behaviour in this actor-network, but there is greater awareness of these pressures and, I believe, a greater desire to overcome these pressures and deliver *the promise*.

The current railway has produced record levels of passenger journeys (Figure 5.22, page 163), but this has taken place on a busy network (Figure 5.24). The COVID-19 pandemic has threatened the viability of densely packed public transport. The role of the railways in UK transport are still worthy of debate (Shaw and Farrington, 2003, p. 131). Whether a debate takes place or not, there should be no doubt that there will be further changes to the concept of the railways, as has happened through the history of the railways.

This chapter has demonstrated that trains and railways can be produced and configured in many ways, with different attributes associated with different collections of resources. Some actor-networks that act as trains will have attributes of excess weight, but this is not an inevitability.

6 Analysis of the Procurement of New Trains using ANT

The empirical analysis in Chapter 4 found supporting evidence that UK trains have been getting heavier over time, as measured by kg per seat. This is the second of two chapters applying Actor-Network Theory to understand the configuration of trains, some of which will have an attribute of excess weight. This chapter focuses upon two recent strategic decisions that have produced new trains for Thameslink and Crossrail. Chapter 4 found that the most recent (tranche four) suburban EMUs, which included the Thameslink Class 700 and Crossrail Class 345, were lighter in weight than their predecessors, albeit with fewer seats available. The strategic decisions for Thameslink and Crossrail have produced trains recognised as a "considerable achievement" (Ford, 2018a, p. 33) in lightweight design.

Chapter 3 explained why these strategic decisions were chosen as a focus for this chapter. Both strategic decisions have completed all steps in the process described in Chapter 2. The Class 700 and Class 345 are *realised* trains providing a service on the Thameslink and Crossrail networks, respectively. These *realised* trains were translated from earlier *propositions* of trains, which were articulated within the Thameslink and Crossrail procurements. In Chapter 2 this strategic decision, including the procurement activity, occurs within a 'place' that was described metaphorically as a *decision-laboratory*. In this *place, propositions* of trains are *articulated,* with the most articulate proposition selected to become a *realised* train. Therefore, the outcomes of these two strategic decisions can be assessed, in terms of the attributes of the realised trains that are central to this research i.e., the weight per seat of the trains.

To understand how trains are produced, this chapter will investigate the procurements – the decision-laboratories – of Thameslink and Crossrail using the theoretical model of five circulating loops (Figure 2.2) first introduced and explored in Chapter 2. This model helps to understand the actor-networks – the collection of resources – involved in the production of propositions of new trains within the decision-laboratory.

The analysis in Chapter 5 used ANT to demonstrate that different concepts of the railway (loop 5, links and knots at the centre of Figure 2.2) have existed over time. This 5th loop acts "like a central knot" (Latour, 1999, p. 100) holding together different networks of resources. The early railways could include trains using horses for power, with carriages hauled on wooden rails of varying width (gauge). The new trains for Thameslink and Crossrail have both been produced during the era of privatisation and this will influence the concept of the railways and how trains act. However, Chapter 5 tells us that concepts are not static and there are many ways to configure railways and trains. Different collections of resources can all act as trains, but with different attributes.

The analysis in this chapter focuses upon the procurements for Thameslink and Crossrail, with the same format adopted in each case. This begins with a brief introduction to the rail network, followed by a summary of the main events and dates regarding the strategic decision to produce new trains. After this there is analysis of the realised trains that have been produced by the two strategic decisions i.e., the Class 700 and Class 345. This analysis used the same approach as Chapter 4 for these specific trains and the trains that they replace. For example, the Class 700 trains replaced 30-year-old Class 319 trains on the Thameslink route, and so a direct comparison is made to understand if weight has increased. ANT analysis is then applied to each procurement – each decision-laboratory – to understand how the *propositions* of trains were produced and how one proposition was selected as a winner to be translated (to become) the Class 700 and Class 345 realised trains. As discussed in Chapter 3, this analysis used secondary data sources to investigate the procurement processes and other aspects associated with these strategic decisions.

In summary, the analysis investigated how *propositions* were developed, and how the *propositions* of Siemens and Bombardier were selected as the *most articulate propositions* in each procurement. If we want trains to be lightweight, then the Class 700 and Class 345 trains provide good evidence that we can achieve this. Our decision-laboratories are the places where we experiment and assemble the trains that we want. This chapter investigates these important places.

6.1 Thameslink and the Class 700s

The procurement of new trains for Thameslink was part of a larger programme to upgrade and expand this part of the UK rail network, forming part of London's north-south commuter network. A schematic of the Thameslink network is show in Figure 6.1 below.

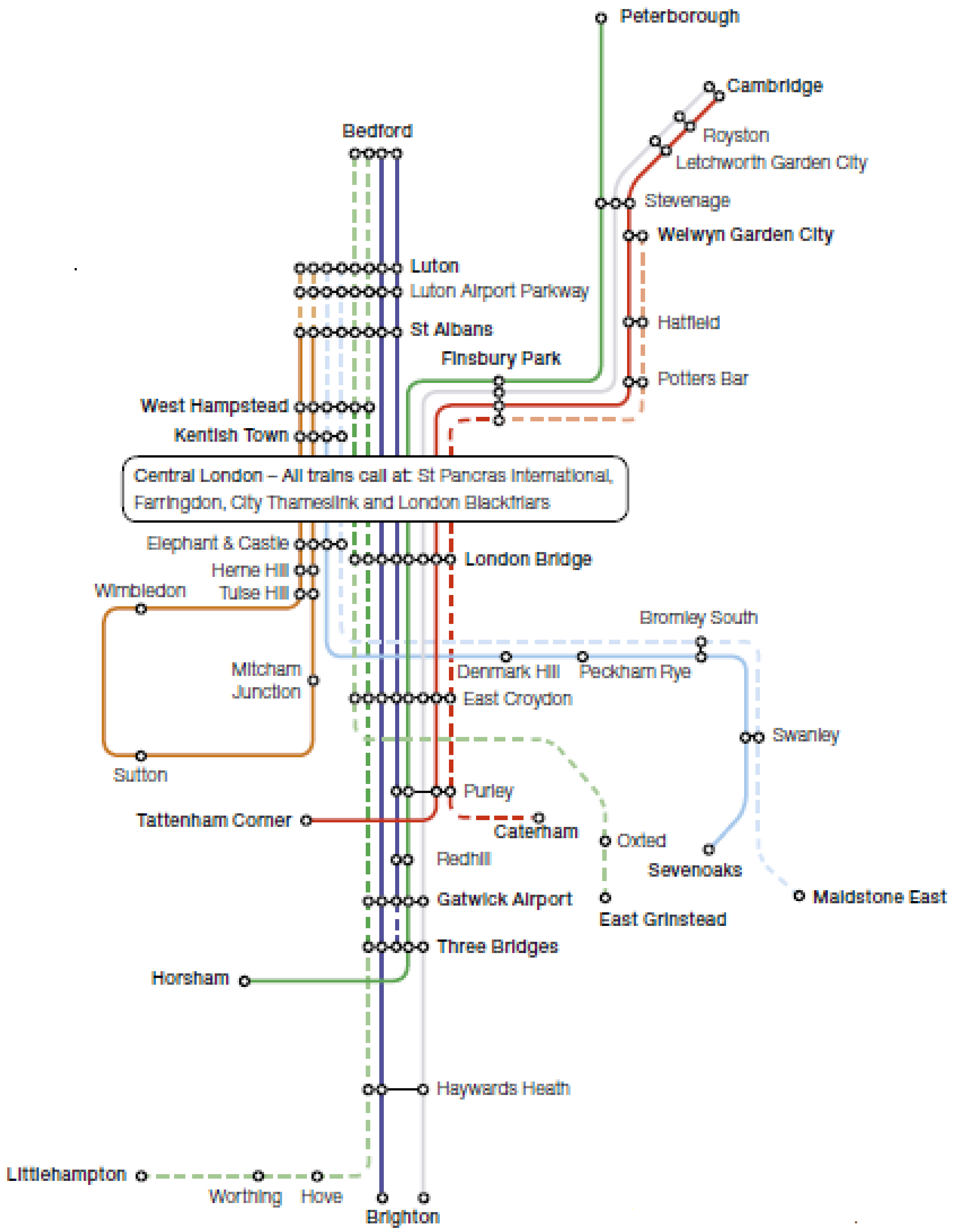


Figure 6.1 Thameslink route diagram

A summary of the dates and key events in the Thameslink Rolling Stock procurement are given in Table 6.1 below. This table provides an overview before subsequent analysis investigating these activities in detail.

Table 6.1 Key events in Thameslink rolling stock procurement

Year	Event
2008	• 9 April 2008: issue of pre-qualification OJEU Notice (Official Journal of the European Union). • November 2008: Government issues Invitation to Tender to accredited respondents
2009	• June 2009: Bids received from Siemens, Bombardier, and Alstom
2010	• 6 May 2010: General Election • June 2010: Spending review. Thameslink paused • November 2010: Thameslink programme reconfirmed
2011	• June 2011: Siemens announced as preferred bidder
2013	• June 2013: Contract awarded to Siemens
2016	• February 2016: First train in service
2018	• June 2018: All trains in service

6.1.1 The realised trains: the outcome of the strategic decision

The introduction of the new Class 700 trains saw six different classes of trains replaced or moved elsewhere. Of these six different classes, there is one – the class 319 – that is specifically mentioned in the Thameslink Invitation to Tender document (Department for Transport, 2008b, p. 52) provided by the Department for Transport (DfT) to bidders. Class 319s are 30 years old and are either being retired or *cascaded* to other parts of the network. For example, Class 319/3 trains were transferred to Northern Rail for newly-electrified lines in the North West of England. The Class 319 is used here to provide a comparison between old and new. Pictures of the exterior and interior of the Class 700 and Class 319 trains are shown below. A visual representation (Figure 6.6) of the Class 700 and Class 319 shows how each car contributes to each trains' total length, number of seats, and weight.

Figure 6.2 Thameslink Class 700 built by Siemens

Figure 6.3 Seating for Thameslink Class 700 built by Siemens

Figure 6.4 Class 319 replaced by Class 700 on Thameslink

Figure 6.5 Class 319 typical seating (3+2 in standard class)

Figure 6.6 Weight and seat profile for Class 700/0 12-car EMU (top) and Class 319/3 4-car EMU (bottom)

Weight (t)	**399.6**	38.2	34.4	36	35.8	26.8	28.3	28.7	27.9	35.6	35.3	34.4	38.2
Seats	**672**	46	54	63	56	64	59	47	64	56	63	54	46
Length	**242.6m**	**20.52m**	**20.16m**	**20.16m**	**20.16m**	**20.16m**	**20.16m**	**20.16m**	**20.16m**	**20.16m**	**20.16m**	**20.16m**	**20.52m**

Weight (t)	**140.3**	29	50.6	31	29.7
Seats	**303**	79	81	64	79
Length	**80.7m**	**20.17m**	**20.16m**	**20.16m**	**20.17m**

Using the same format as the chart that prompted this research (Figure 1.5), the Class 700 EMUs for Thameslink, and the replaced trains, are shown in Figure 6.7 below.

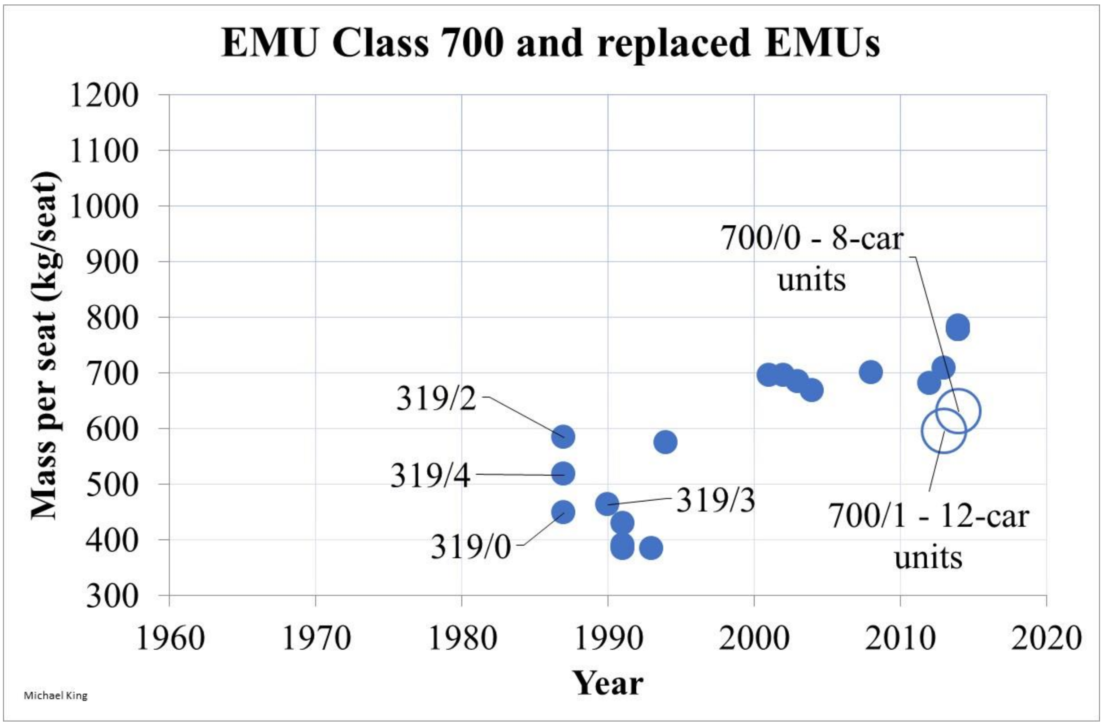


Figure 6.7 Class 700 EMUs and the trains they replaced (kg/seat and year of introduction)

There are two sub-classes of the Class 700 – an 8-car set (700/0) and a 12-car set (700/1). A visual inspection shows that the Class 700 trains are lighter per seat than some of the units they are replacing, but heavier than others. Some classes replaced by the new Class 700s are shown but not labelled. The four sub-classes of the Class 319 are labelled in the chart, and will be explored in more detail, as it was referenced by the DfT as a comparison train. Table 6.2 below contains the information for the Class 700 and Class 319 trains used to make the chart above.

Table 6.2 Weight and seat data for Thameslink Class 700s and the Class 319s they replace

	Cars per trainset	Seats per trainset	Weight of trainset	Average car weight (tonnes)	Seats per car	Weight per seat (kg/seat)
700/0	8	433	273.5	34.2	54.1	**631.6**
700/1	12	672	399.6	33.3	56.0	**594.6**
319/0	4	304	136.5	34.1	76.0	**449.0**
319/2	4	243	142	35.5	60.8	**584.4**
319/3	4	303	140.3	35.1	75.8	**463.0**
319/4	4	267	138.3	34.6	66.8	**518.0**

This table shows that the new Class 700s are heavier per seat than all class 319s. The 8-car Class 700/0 has 433 seats and weighs 273.5 tonnes in total, giving a figure of 631.6 kg/seat. The 12-car set has 672 seats and weighs 399.6 tonnes, giving a figure of 594.6 kg/seat. However, the Class 319/0 is the lightest per seat. It is a 4-car unit with 304 seats and weighs 136.5 tonnes, giving a figure of 449.0 kg/seat – lighter per seat than either of the new Class 700s. To investigate this further, like in Chapter 4, we can break the metric of weight per seat into its component parts.

Table 6.2 shows that the average weight of a Class 700 12-car is the lightest, at 33.3 tonnes per car, and the 8-car Class 700 is lighter than all bar one of the Class 319s. However, the Class 700s have an average of 54-56 seats per car, whereas the Class 319s vary between 60-76 seats per car. Some of this reflects the higher density 3+2 seating used in Class 319s, as shown in Figure 6.5 above.

The new Class 700 trains have a lightweight design, albeit with fewer seats per car than their predecessors.

The next sections explore how this came about, focusing upon the Thameslink procurement where propositions of trains were articulated and one was selected to become the realised train described above.

6.1.2 Activities before the procurement

As discussed in Chapter 2, the exact starting point of a strategic decision is difficult to define. Improvements to the Thameslink network were first investigated by British Rail in the 1980s and 1990s. Thameslink services were consistently among the most crowded London routes (loop 4, public representation). British Rail made unsuccessful proposals to Government to increase capacity in 1989, with further proposals submitted later by Railtrack. When Railtrack was put into administration in 2002 the Strategic Rail Authority (SRA) took over, until it was abolished by the Railways Act 2005. In the modern privatised railway, the identification of a sponsor to take over from the SRA raised problems.

At the end of Chapter 5 the privatised concept of the railway (loop 5, links and knots) was described as *functional specialisation with contractual integration*. The rolling stock companies (ROSCOs) were created at privatisation specifically to manage long-term ownership of rolling stock in the privatised railway. These specialist organisations competed to lease their rolling stock to the Train Operating Companies (TOCs). The TOCs had contracts with Network Rail to operate these trains on the network. The privatised concept used contractual incentives and charges to integrate the railway service. The TOCs pay *access charges* to Network Rail for access to the rail network and to compensate for the wear and tear associated with usage and damage caused by different types of rolling stock. Network Rail manage ongoing maintenance and improvements to the network. Damage caused by rolling stock would be expected to incur higher access charges, which would make it potentially less attractive to TOCs, and so ROSCOs would have an incentive to manage this industry cost.

The importance of managing life-time costs for long-lived assets, such as trains, was a known issue within the industry. There was increased recognition that costs needed to be managed across the whole rail system. The capital costs to build new trains were important, but managing total costs was vital because nearly 40% of total costs “goes on maintaining and operating trains over their lifetime” (National Audit Office, 2014c, p. 18). However, access charges bore “little relation to the specific costs that they impose” (Department for Transport, 2004, p. 19).

Strategic decisions, like the Thameslink Programme, exposed problems with the privatised concept of the railways. Specialisation could begin to look more like fragmentation, because costs and benefits cut across various institutions and processes and achieving the ‘best’ outcome for the industry, rather than individual organisations became more challenging. The ROSCOs were intended to manage rolling stock, but this procurement was on a scale that exceeded the capacity of any single ROSCO. Additionally there were also concerns at the time regarding the leasing market, with the Office of Rail Regulation (ORR) referring the market to the Competition Commission in 2007 (*Rolling Stock Leasing market investigation*, 2009).

Network Rail were a candidate to take over as Project Sponsor. Upgrading the infrastructure for the Thameslink Programme was primarily their responsibility as the *specialist* railway infrastructure manager. However, although Network Rail owned and operated some trains used for maintenance and renewal work, they did not own the bulk of UK trains, and they did not operate passenger services. They would be involved in the Thameslink decision to procure new trains, because the trains would run on their infrastructure, but they would not lead it.

The Train Operating Companies were a candidate for Project Sponsor, because they provide the drivers and other staff to deliver the railway services that would use the new trains and upgraded infrastructure. However, the new trains were to operate across three existing franchise geographies, which made it difficult for any single TOC to take a lead on the procurement. Even if a TOC could be chosen, there was still a problem regarding their transitory and relatively short-term nature. A TOC with a limited franchise duration might favour short-term outcomes, even when making decisions on new trains with an expected 30+ year life.

The institutions of TOCs and Network Rail acted in this strategic decision, as did contractual incentives, such as access charge payments. None of these institutions were able to take on the role of early sponsor. The succession of rail industry sponsors from BR to Railtrack and then the SRA (National Audit Office, 2013, pp. 5, 12) concluded in July 2005, when the Department for Transport became the active sponsor of the Thameslink programme, including the procurement of new trains. **This strategic decision required a long-term and whole industry perspective, that spanned infrastructure and train services.** This had been provided by British

Rail and later by the Strategic Rail Authority. BR no longer existed after privatisation, and the SRA was abolished in 2004, therefore the DfT took on this role for the Thameslink Programme and procurement of new trains.

The Department for Transport can be considered a Prime Mover (Latour, 1999, p. 182) in the strategic decision to produce new trains. They have a clear early role in shaping the early actor-network as it develops, but this does not mean they are solely responsible for the action. As discussed in Chapter 2, to manage the potential open-endedness of networks, the idea of a Prime Mover can be helpful. This Prime Mover entity is instrumental in assembling the network: defining the problem, engaging the interest of others, and allocating roles (Callon, 1984, p. 6). However, it would be an incomplete ANT analysis to say that the DfT are *responsible* for making the strategic decision that produced new trains. They are simply part of a larger performance, even if they are an important actor.

When the DfT took over from the SRA it commissioned an updated business case. The main objective of the Thameslink Programme had remained in place since the 1980s – **to increase capacity and thereby support the rapid transport of passengers in and out of London**. Increased capacity was to be achieved by running higher frequency, longer trains on an expanded and enhanced infrastructure, including longer platforms and other improvements that would collectively act to deliver the increased capacity. The DfT estimated benefits of £2.9 billion (National Audit Office, 2013, p. 5) deriving from reduced journey times, reduced crowding on trains and quicker interchanges between services. The strategic decision is made stronger by these modelled benefits that are mobilised (loop 1, mobilisation of the world) and brought into the action. DfT subsequently decided to proceed with the Thameslink programme in 2007. The fleet of new trains, with two new maintenance depots, had an estimated capital cost of £1.6 billion, which the DfT planned to finance through a private finance initiative (PFI).

The network of actors involved in the production of these new trains was about to develop, as the DfT published a notice in the Official Journal of the European Union (OJEU). New actors were about to be enrolled with this public notification of the procurement process that was about to begin.

6.1.3 Early actor-network development: the OJEU is issued in April 2008

On 9 April 2008, a notice was published in the Official Journal of the European Union to alert potential suppliers to the coming procurement. A copy of this notice is shown in the Appendix (page 351). The OJEU notice states that the DfT is doing it *on behalf of the train operating company* (TOC) operating the Thameslink franchise. The Department's role is to "ensure that the rolling stock gets built (i.e. it puts out the procurement) and then it guarantees that the stock will be leased by a TOC over a certain period" (Butcher, 2017, p. 12), with the final contract likely to be with the TOC, and not with the DfT.

The information in the OJEU notice supports early actor-network enrolment by asking for *expressions of interest* from organisations able to supply and maintain a fleet of new rolling stock, expected to range from 900 to 1300 new vehicles. However, the OJEU bundles more than just passenger-carrying trains into the actor-network. It is possible, but not certain, that new depots to support the trains will be included. The provision of financing for the trains and the depots is also part of this action. This articulation of new trains requires that the "winning bidder establishes a Special Purpose Company (SPC), which…then raises the funds required to build and maintain the stock" (Butcher, 2017, p. 12), with the SPC owning the rolling stock. This is effectively creating a mini-ROSCO and a potential new competitor to the three existing ROSCOs that owned c. 90% (Butcher, 2017, p. 5) of rolling stock at this time. The OJEU notes that financing may be subject to change, which may reflect the timing of this request, in 2008, when the global financial crisis impacted credit markets across the world and the ability of organisations to raise financing. At this stage in the process the developing actor-network to produce new trains may, or may not, involve the production of depots and the provision of private financing.

When it comes to *why* the trains are needed, the OJEU directs interested parties to supporting documentation available on the DfT's website. Capacity issues are clearly evident, with the procurement described as "a major initiative to provide additional capacity and remove bottlenecks on the London commuter network" (Department for Transport, 2008c, p. 4). DfT is looking for *expressions of interest* from organisations that can help to produce trains with attributes that help to address capacity problems. DfT, as Prime Mover, is defining the problem and drawing interested parties into this developing actor-network – a process of *problematisation* and *interessement* (Callon, 1984, p. 8) that develops and shapes the actor-network. Interested parties are enmeshed in relationships by the DfT when, for example, they are told that they must work with *Network Rail, the TOC, and other relevant parties* to ensure train acceptance and full operational approval for the realised trains to be allowed to use the UK rail network.

Although the OJEU notice does not give a lot of information regarding the desired future trains, it does provide some specific guidance regarding certain attributes. For example, they must be dual voltage, which means that they can operate on rail networks with 25kV AC power, supplied by overhead lines, and 750V DC, supplied by a third rail. The predecessor Class 319s were also dual voltage. This reflects their operating area, which includes both AC and DC supply. The trains need to *act with* the local infrastructure.

The notice provides the following set of high-level requirements that the desired trains are expected to deliver:

c1. A safe, consistently reliable journey.

c2. An environmentally sustainable solution.

c3. Customer expectations on ambiance, amenities, and facilities

c4. Whole life/whole system value for money, and, compared to the existing Thameslink fleet

c5. Increased capacity per train

c6. Increased capacity on the network

c7. Improved safety and security.

Early *problematisation* (Callon, 1984, p. 6) around capacity is visible in this list (c5, c6 above), but a broader set of desired attributes for the trains are also articulated, including reliability, environmental sustainability, customer experience, safety and security.

The OJEU notice provides the timetable for this strategic decision. The deadline for expressions of interest is 9 June 2008, two months after the publication of the OJEU notice. Expected contract award is stated as mid-2009 (actual: June 2013), with new trains (*realised* trains) expected to start in passenger service February 2012 (actual: February 2016).

A final analytical point to highlight regarding the OJEU notice relates to the stated *award criteria*, which is defined as the *most economically advantageous tender in terms of the criteria stated in the specifications or in the invitation to tender or to negotiate*. Under EU law, procurement can be based on price alone, or on the broader basis of the ‘most economically advantageous tender’ (MEAT) (House of Commons Transport Committee, 2011, p. 12). The definition of MEAT is not given here but will be developed as the procurement process unfolds – typically this uses scoring criteria allocated to different aspects of the process. The propositions of trains will need to *articulate with* the criteria defined for MEAT if they are to be selected as the winner. This will be explored further later, as the definition of MEAT is developed in more detail and shared with bidders.

Organisations expressing an interest are required to respond using an Accreditation Questionnaire (AQ) (Department for Transport, 2008a) provided as part of the supporting information on the DfT’s website. In addition to the AQ there are also various presentations, industry briefings, and processes to raise questions and receive answers. Only Applicants that are successfully accredited are eligible to receive an *Invitation to Tender* (ITT), which is the next stage of the procurement competition to produce propositions of trains. At this stage it is not propositions of trains that are being evaluated, but the suitability of institutions expressing an interest to participate. The AQ document asks a range of questions regarding characteristics of the respondent organisations and their ability to fulfil the requirements of this notice. The structure of the AQ, and the associated scoring for each section, is shown in Figure 6.8 below.

Section	**Score**
Applicant's Introductory Statement	Not Scored
Section A - Applicant Information	
1 Applicant Information	Pass / Fail
2 Governance Details	Pass / Fail
3 Safety Record	Pass / Fail
Section B - Financial Standing	
1 Financial Information	Pass / Fail
Section C - Business Excellence and Approach	
Results Criteria	
1 Customer Results	20%
2 Key Performance Results	15%
3 People Results	9%
4 Corporate Social Responsibility	6%
Enablers Criteria	
5 Leadership	10%
6 Policy & Strategy	8%
7 People	9%
8 Partnerships & Resources	9%
9 Processes	14%
Total for Section C	**100%**
Section D - Technical Capability and Experience	
Design	25%
Manufacture	10%
Testing, Commissioning and Customer Acceptance	10%
Maintenance and Service Provision	20%
Depot Design and Construction	5%
Programme Interfaces	8%
Compliance	5%
Commercial Approach and Contract Management	9%
Financing Capability and Experience	8%
Total for Section D	**100%**
Aggregation of Section C and Section D **The scores for Sections C and D will then be combined into a weighted aggregate with relative weightings of 40% for Section C and 60% for Section D**	

Figure 6.8 Structure of the Thameslink Accreditation Questionnaire

Sections A and B of the AQ relate to the character and financial standing of the responding organisations. This is a pass or fail set of questions. For example, the three-year average turnover for the manufacturing constituent of the Applicant must meet a minimum annual threshold of £0.5Bn, if they are to take part in this process. With an expected value for this procurement of c. £1.4Bn, the AQ *acts to enrol* (Callon, 1984, p. 10) suitably large organisations into this network. The large organisations may have smaller institutions within their consortium, but the lead role is only open to institutions with certain attributes.

Sections C and D are scored, with section C attracting 40% of the weighted aggregate score and Section D the remaining 60%. There are different weightings attached to sub-sections, with, for example, *Design* receiving the most in Section D at 25%. There is no information regarding how these weightings were produced, but, like an exam paper, it would be reasonable to expect that respondents would ensure that their *answers* – their propositions of trains – are articulated in relation to this scoring scheme.

Section C is structured around something called the *Business Excellence Model,* which was created by the European Foundation for Quality Management (EFQM). The EFQM Business Excellence Model is mobilised and brought into this action (loop 1, mobilisation of the world), but it is not opened up or explored in any detail and is effectively treated as a *blackbox* (Latour, 1999, p. 70) that is to be accepted by participants. The EFQM Model provides a structure for Section C of the AQ that *acts to choose* among interested parties. Section C uses the nine EFQM categories – five for *enablers* and four for *results* – with a brief 1-2 sentence description, taken from the EFQM literature, given for each of the nine criteria. The response to Section C is limited to a maximum of 30 pages of A4.

Section D attracts 60% of the weighted score and is broken into nine sub-sections to assess the *Technical Capability and Experience* of the respondent. Respondents are asked to give references of prior work, similar in scope and objectives to Thameslink. The response for section D is limited to a maximum of 70 pages.

The AQ has no explicit reference to weight, or the number of seats, of the desired trains, however, energy and environmental considerations do occur in the document. Section D1, *Design*, asks the respondent to give prior examples demonstrating "how new technology was used to improve energy efficiency." Section D6, *Programme Interfaces*, asks for examples of how "environmental considerations were managed within your projects" and D7, *Compliance*, asks for experience "working to International Environmental Standards."

In response to the OJEU notice, five organisations expressed an interest. Four were subsequently accepted by DfT and, in November 2008, the Invitation to Tender (ITT) documentation was issued to "Alstom Transport, Bombardier Transportation, Hitachi Rail (Europe) and Siemens plc" (House of Commons Transport Committee, 2011, p. 48). These four bidders, with their partners and specialist suppliers, are part of different and competing actor-networks. They will come together with other actors within the decision laboratory to produce competing propositions of trains for Thameslink. These other actors will include other human (social) actors, such as Network Rail, passengers, and so on. It will also include non-human actors, such as the local electrical supply, the tunnels, the weather, and more.

The Rail Minister, Tom Harris said at the time, “These new lighter, greener trains will benefit passengers on some of the busiest commuter services” (Rail Technology Magazine, 2008). Proposition development is about to move into the ITT phase, where competing propositions will be articulated in much more detail.

6.1.4 The development of articulate propositions of trains: the ITT is issued in November 2008

The ITT was the next stage in the production of the Thameslink Class 700 trains. One of the four organisations invited to participate, Hitachi Rail, decided to withdraw so that they could concentrate on another large procurement for the Intercity Express Programme. This left Alstom, Bombardier, and Siemens, together with their associated partners and advisers. These companies were leaders of competing bid consortia that brought existing capability in the delivery of trains, depots, maintenance, and financing. Siemens based their core offer around their *Desiro City* model, Bombardier their *Aventra* design, and Alstom their *X’Trapolis* train.

The DfT issued a range of documentation regarding their requirements, and to explain how the procurement process would work. A *clarification process* between DfT and bidders begins with the launch of the ITT, in November 2008, and runs until bids were required to be submitted, which was stated as April 2009 (actual June 2009). This clarification process is part of a collaborative effort to articulate propositions that will continue throughout this action.

The documentation provides objectives for the Thameslink Rolling Stock Project (TRSP) (Department for Transport, 2008b, p. 19) that are broadly similar to those stated earlier in the OJEU stage:

(a) deliver increased capacity on the rail network
(b) deliver a reliable journey time

(c) meet customer requirements by providing an enhanced passenger environment
(d) improve safety
(e) deliver an environmentally sustainable solution
(f) minimise whole-life, whole-system cost
(g) offer flexibility of deployment
(h) manage the transition during the replacement of existing fleets

The need to deliver more capacity is identified first, but these objectives are not described as hierarchical, or prioritised. The objectives also include the delivery of *an environmentally sustainable solution* (item 'e' in the list above), but the meaning of this is not given.

The Department directs bidders to connections and relationships that must be made in the articulation of propositions. Appendix O of the provided ITT documentation provides the following list of stakeholders:

1. Department for Transport
2. Operator and Initial Operator – reflecting changes in the boundaries of the operating franchises in the area
3. First Capital Connect Limited (FCC) – the initial Operator
4. Network Rail – an integral part of the TRSP team and responsible for the delivery of the Thameslink infrastructure
5. Office of Rail Regulation (ORR) – Her Majesty's Rail Inspectorate (as part of the ORR) has a role as safety authority and ORR also oversees regulated agreements including depot access agreements
6. Rail Safety and Standards Board (RSSB) – the independent body that sets standards for the UK mainline railway
7. Passenger Focus and London TravelWatch – key stakeholders in the development of the specifications

The stakeholders identified in the list above are all industry institutions. Propositions will be strengthened if they reach out and connect this group (loop 2, autonomization) of industry professionals and colleagues into the process of articulation. Passenger Focus and London TravelWatch are industry institutions that also *represent* passengers (loop 4, public representation) in the articulation of propositions of trains.

Bidders' requests for stakeholder meetings with this group are expected to be made via, and managed by, DfT. Questions and answers to the DfT are made visible to all bidders by default, and bidders know this in advance of submitting their questions. Procurement legislation, requiring an open and transparent process, is likely to be acting here.

The documentation supplied to bidders includes three technical specifications that describe the desired trains and their attributes. These are the Train Technical Specification (TTS), Train Control Specification (TCS), and Train Infrastructure Interface Specification (TIIS). The TTS documents the requirements for the trains, the TCS documents the control systems onboard the trains that interface to control systems on the rail network, and the TIIS documents the infrastructure on which the trains will run. For a train to act it must work collectively with the surrounding infrastructure and local systems. These documents are central to the procurement and articulation of propositions within the decision-laboratory.

The Train Technical Specification (TTS) was created by a company called Interfleet Technology Ltd for the DfT. This document represents the *desired future train* in **more than 500 unique TTS identifiers** describing various characteristics. Bidders are required to articulate their proposition using the same structure – this is how the complex socio-material thing called a train will be simplified and measured (loop 1, mobilisation of the world) for the purpose of evaluation within the decision-laboratory environment. The TTS will be explored in detail later in this analysis, but some examples are shown below. These examples illustrate the range of actors – human and non-human – collectively acting as the propositions of trains are being produced and articulated:

- TTS 4.1.1: The Thameslink Units shall comply with the requirements of all applicable British and European Standards, and all relevant European and UK legislation at the time of contract.
- TTS 5.1.2: Units shall be manufactured, delivered, and operated in two different lengths to meet different service requirements.

- TTS 6.7.2: The capacity of the Unit windscreen wash system shall support a minimum of three days of Thameslink service operation between top ups.
- TTS 8.11.9: The Unit shall be designed for optimal recyclability.
- TTS 9.1.1: The Unit shall have a design life of not less than 35 years.

The Train Infrastructure Interface Specification (TIIS) was written by Network Rail (NR), who are responsible for rail infrastructure in the UK. NR also leads on infrastructure development for the wider Thameslink programme to re-develop stations, extend platforms, etc. The TIIS *represents* the infrastructure on which the trains will operate – the tracks, signals, stations, platforms, and other components. The information in this document describes the local gauging (spacing) in tunnels, gaps to platforms, the availability of AC power from overhead lines, or DC power from 3rd rail supply, and other attributes. There are **more than 250 unique TIIS identifiers** to represent attributes of the future trains and their interface to infrastructure. If they are to act successfully as a train, then the propositions being developed must articulate with the surrounding infrastructure as represented in the TIIS. The complexity of the real-world infrastructure has been mobilised, in these 250+ identifiers, and brought into the decision-laboratory (loop 1, mobilisation of the world) for the purpose of experimentation and proposition development.

The Train Control Specification (TCS) was also written by Network Rail and relates to the systems that control the train’s operation, which also interact with systems that manage regulation of all trains in the area. A new train control system is required to deliver the key capacity objective of the Thameslink Programme, with a goal 24 trains per hour at stations in central London – one train every 2-3 minutes. There are **more than 150 unique TCS identifiers** that describe the attributes of the control systems onboard and their interfaces to wider network control.

These documents are an important part of the action to produce new trains, however, bidders are not starting from a blank sheet of paper. They have been accepted as participants in this action because of existing capabilities assessed at the previous stage. **Existing propositions of trains from each bidder are connected to, or articulated with, these specification documents and the wider action taking place in the decision-laboratory.**

As propositions are articulated, the ITT includes four stages to evaluate their progress and suitability to proceed to the next stage:

1. Stage 1 – Mandatory Requirements
2. Stage 2 – Evaluation of Proposals
3. Stage 3 – Project Deliverability
4. Stage 4 – Value Assessment

6.1.4.1 ITT stage 1 – mandatory requirements

A subset of criteria from the specification documents must be satisfied by Bidders and their propositions to be considered further. Of the 500+ identifiers in the Train Technical Specification (TTS) there are 90 deemed mandatory to pass stage 1. This mandatory list is shown in the appendix (page 357). Some mandatory criteria represent the characteristics of the local network and infrastructure as it is now because this is not expected to change. For example, “Units shall be capable of operating over both the Network Rail 750V DC 3rd rail and 25kV AC electrified systems” (TTS 6.3.1). Other mandatory criteria reflect the infrastructure as it will be in the future. For example, longer platforms do not exist now, but the competing propositions of trains are tested against them. “Full Length Units shall not exceed 243m in overall length between coupler faces” (TTS 5.1.3).

Directly relevant to this research is the seating and passenger carrying capacity. The capacity required of the trains is shown below in Table 6.3 and detailed in TTS 5.2.1, which requires that: “Each Unit shall provide at least the capacity given in the table below whilst simultaneously meeting the dwell time requirements of clause 6.6.”

Table 6.3 Minimum level of seating, standing and luggage capacity identified by DfT for Thameslink trains

	Full length Unit ('Outer' configuration)	Reduced length Unit ('Outer' configuration)	Reduced length Unit ('Inner' configuration)
Standard seats	572	364	418
1st class seats	48	48	0
Face to face tables	10 (1st class only)	10 (1st class only)	0
Luggage module capacity (litres)*	24,000	16,000	16,000
Luggage utility modules per vestibule	1	1	1
Cycle utility modules per Unit	2	2	2
Standing capacity**	1100	800	800
Toilets	5 (including 1 universal access toilet)	3 (including 1 universal access toilet)	3 (including 1 universal access toilet)

This desired attribute of the proposition of a train, as articulated by DfT and others in the TTS in 2008, can be compared to the Class 700 realised trains that entered service in 2016. The Class 700/0 8-car trains (reduced length in the table above) have 433 seats in total, consisting of 52 in first class, 364 standard class and 17 additional tip-up seats. This exceeds the requirements for first class seating, given in Table 6.3 above, whilst meeting the number of standard class seats exactly, with 17 additional tip-up seats. The Class 700/1 12-car trains have 672 seats in total, consisting of 52 in first class, 602 standard class and 18 additional tip-up seats – exceeding the requirements for first and standard class seating. The requirements for seating are mandatory and so Bidders, that want to progress beyond stage one, must articulate their propositions with these attributes. The attributes, as described in the TTS and other documents, are acting collectively with the Bidders and other actors to shape the configuration of resources that act as propositions of trains and later become realised trains carrying passengers. The *realised* trains produced by Siemens, that are *translated* from the early winning *proposition*, have attributes that are more than *articulate* with this mandatory requirement.

The mandatory requirements for seating (TTS 5.2.1) also refer to *the dwell time requirements of clause 6.6*. TTS clause 6.6 includes four sub-clauses (TTS 6.6.1-4), which are mandatory requirements relating to *station dwell time* i.e., how long the train stops at a platform to board and un-board passengers. Propositions of trains must articulate with the mandated seating capacity, but this cannot impact their ability to load and unload passengers as fast as possible to meet the capacity throughput required. A 45 second dwell time is a key goal for Thameslink, to support high levels of throughput in the central London stations.

Another example of a mandatory requirement relates to desired reliability levels of the propositions. With TTS 7.1.3 we see that reliability is measured (loop 1, mobilisation of the world) using a standard established by the British Standards Institution, *EN50126-1:1999*, or an equivalent approved framework. Standards *act* in the articulation of propositions by defining and measuring different attributes of the propositions – like the weighing machine at Rainhill in 1829. Propositions of trains will be articulate, or not, according to such measurement systems.

The final point to note from stage 1 of the ITT is that weight is not a mandatory requirement. Weight will be introduced into the articulation of propositions during stage 2.

6.1.4.2 ITT stage 2 – evaluation of proposals

Stage 1 reviewed bidders’ proposals (propositions of trains) against a subset of the specifications identified as mandatory. The second stage evaluates propositions against the wider set that also includes depots and financing required in this collective action to produce new trains. Evaluation scores are weighted 70% for technical requirements and 30% for financial deliverability, as shown below:

- Technical Requirements (70%)
    - Train Technical Specification (TTS) (60% weighting)
    - Train Infrastructure Interface Specification (TIIS) (20% weighting)
    - Train Maintenance and Depots Technical Proposal (20% weighting)
- Financial Deliverability (30%)
    - Funding Deliverability: *extent to which the financing proposal demonstrates that there is full and unconditional commitment in place from all providers of finance* (Department for Transport, 2008b, p. 38).
    - Financial Robustness: *an evaluation of the Bidder's hedging strategies and any parent company guarantees, standby facilities, bonding arrangements and insurance arrangements* (Department for Transport, 2008b, p. 39).

The allocation of 30% to financial deliverability demonstrates that the production of the new trains is not just about steel wheels, bogies, and traction. The translation of the most articulate proposition of a train into a realised train requires financial capital because there is likely to be several years of expense before the trains enter operational service and begin to generate revenues. This financial part of the production brings in an associated cast of actors. The actor-networks producing propositions of new trains in the decision-laboratory now also includes equity and debt providers, and others providing guarantees and capital to manage risk. The competing actor-networks reach out beyond the railway industry to form alliances (loop 3, alliances) that can strengthen their networks, through, for example, the provision of better financing terms.

The technical assessment of propositions receives 70% of the score. The bulk of this (60%) is given to the TTS – the Train Technical Specification – and this will be explored in detail in the rest of this section. The balance of the technical scoring is given to assessment of the TIIS (20%) and proposals for the depots and maintenance (20%) to support the trains during their service. Maintenance and depots are not explored in detail in this research, given the focus upon train seats and train weight, however the competing bidders need to articulate this within their proposals.

The TIIS was discussed briefly earlier. It *represents* the external infrastructure on which the future trains will operate. Effectively, the propositions of trains will *run* on this represented infrastructure. The TIIS mobilises aspects of the external world (loop 1, mobilisation of the world) and brings it into this experimental environment to produce new trains. For example, the TIIS brings in London underground tunnels through which the trains will operate. These tunnels are very tight, and so emergency exits (TIIS_1958) need to be able to use the ends of the train, rather than the sides like other trains. In addition to tunnels and other infrastructure, the TIIS also brings people who live near to the railway lines (loop 4, public representation) into the action. Requirements focused upon *operational interfaces* include a desire (TIIS_1760, TIIS_1761) to reduce the noise of train wheels for neighbours.

The largest weighting (60%) of the technical assessment is measured against 543 requirements contained in the Train Technical Specification (TTS), which includes the 90 mandatory criteria reviewed previously. Stage 2 assesses the remaining requirements and allocates weightings across these criteria. The detailed scoring matrix for the TTS is shown in the appendix (page 360 onwards). As an example of the level of detail, item 10.23 defines the desired characteristics of the Windscreen Wiper System with TTS 10.23.1 stating that the *windscreen wiper system shall include an intermittent wipe facility.* The scoring matrix in the appendix (page 357) shows that TTS 10.23.1 attracts 1% of the total scoring for category 10 within the TTS, which covers a range of characteristics grouped under the title, *system functions*. This category, *system functions,* is allocated 15% of the total marks for the Technical Train Specification. As stated above, the TTS reflects 60% of the total Technical Requirements, and the Technical Requirements is 70% of the total score, with 30% allocated to the financial deliverability. This implies that a maximum score on windscreen wipers for a bidders' proposition is worth some 0.06% of the total score, which suggests that it is part of the articulation of a train that is taking place, even if it is obviously not the most important part!

The TTS has 500+ desired characteristics and attributes, which include other specific requirements. TTS 5.2.6 requires that: *Each Full Length Unit shall be fitted with five toilets including a universal toilet compliant with the PRM TSI.* TTS 6.2.1 requires that *Each Unit shall be capable of a maximum speed of 100mph (160km/h) on level tangent track when travelling into a head wind of 60km/h.* TTS 9.1.1 states that *The Unit shall have a design life of not less than 35 years.*

The specification often includes a definition of the measurement system to be used for specific attributes. For example, TTS 6.1.10 defines a requirement for *…at least* *a 9.5% reduction on the actual journey running times for the current Thameslink Class 319 Unit when operating on the AC power supply network part of a Bedford to Brighton semi fast diagram.* The measurement system for journey time is defined relative to a specific predecessor train (Class 319), and on a specific part of the network (Bedford to Brighton). This route and the Class 319 are brought into the action (loop 1, mobilisation of the world) to *represent* all journeys that the realised trains will operate. The propositions are assessed against this abstract and simplified representation of the entire network.

Energy use is important for the focus this research, and category 8.3 of the TTS describes the *Energy Use and Efficiency* of the desired trains in 17 separate requirements (TTS 8.3.1 to TTS 8.3.17), including the need for energy recovery during braking and other characteristics. Net energy consumption (including regeneration) is described in TTS 8.3.1, which defines the requirement as: *an improvement of at least 15% in net energy consumption, over current design rolling stock using regenerative braking operating a Bedford to Brighton semi fast diagram*. Once again, we see the measurement system defined using a specific route (Bedford to Brighton), and type of service (semi-fast). Bidders are also instructed (TTS 8.3.1) that *for the purposes of this calculation, the AC and DC power supply networks* ***shall be considered to be 100% receptive*** [emphasis added]. Energy recovery from onboard regenerative braking systems may not work if the electricity supply networks are unable to receive the power from the train. However, **propositions are articulated and operate in a modelled world that does have receptive networks, rather than the present real world, which may not be able to receive regenerated power.**

The comfort of trains also has a measurement system. Category 8.4 describes aspects of the *Ride Quality* of the desired train. There are five requirements identified (TTS 8.4.1-5) with TTS 8.4.1 requiring that *Unit ride quality shall achieve a mean comfort index of 2 based on the ENV 12299:1999 Ride Comfort for Passengers, Measurement and Evaluation.* This references a European standard first published in 1999, based upon research by UIC (International Union of Railways, or Union Internationale des Chemins de fer) and British Rail Research. This standard, created by railway institutions, represents passenger comfort (loop 4, public representation) within this action to produce new trains.

The ability of the trains to carry passengers is defined in Category 5.2 (*Unit Capacity*) across nine separate requirements (TTS 5.2.1-9). One of these (TTS 5.2.1) was a stage 1 mandatory requirement for the minimum number of seats. Stage 2 articulates this capacity attribute of the desired trains in further detail. The guidance contained in TTS 5.2.4 provides the measurement approach to be used to calculate the capacity of the proposed trains, and it is worth reproducing in full below:

> **Three plus two seating arrangements are not permitted in any configuration.** [Emphasis added]
>
> Tip up seats can only be included in the seat count once the minimum number of conventional seats and the space necessary for the minimum standing capacity required by TTS 5.2.1 has been achieved.
>
> The space used by the occupied tip up seat shall be included in the seat count calculations unless it is primarily required for wheelchair passengers or is required for the minimum standing space calculation. It may not be double-counted for seat and standing capacity.
>
> **Standing capacity shall be calculated at 4 passengers per square metre of usable standing area.** [Emphasis added] Usable standing area is defined as the aggregate of all areas of floor within the Unit greater than 0.25m² and with no fixed obstruction from the floor to a height of 1800mm and where suitable hand holds are provided to allow passengers to safely stand.

Here we see some extremely specific articulation (forbidding 3+2 seating). This can help to explain the reduced seating of the realised Class 700 trains relative to their predecessors, that was discussed earlier (section 6.1.1) and in the empirical analysis of Chapter 4. Some predecessor trains, such as the Class 319, did use 3+2 seating in some standard class layouts, whereas the new trains were not permitted this configuration. The Bidders could have ignored this, but then their propositions would be inarticulate with respect to the collective action to produce new trains taking place in the decision-laboratory.

It is likely that this guidance regarding 3+2 seating was driven by research conducted by PassengerFocus and London Travel Watch for the DfT that was made available to

Bidders. Passenger Focus (now called Transport Focus) is the independent passenger watchdog, set up by the UK government. London TravelWatch is the official watchdog organisation representing the interests of transport users in and around London. They conducted research with 93 passengers and interviews with nine passengers with various disabilities. A key finding (Passenger Focus and London Travel Watch, 2008, p. ii) was that "'Three plus two' seating was universally unpopular with passengers because of the practical and social 'awkwardness' of getting in and out of the window and middle seat." Passengers, *represented* by this qualitative research and these institutions, have been mobilised, and brought into the decision-laboratory (loop 4, public representation). These passengers, as represented in research, have acted to shape the propositions of trains, as evidenced by the lack of 3+2 seating in the Class 700 realised trains produced by Siemens.

TTS 5.2.4 described above also defines the measurement approach for standing capacity with *4 passengers per square metre of usable standing area* defined as the calculation that Bidders should use. This is how the proposition of a train is to be *measured and modelled* and does not necessarily reflect how many passengers will stand and squeeze onto the realised train during busy periods of *actual* use.

Weight was not a mandatory requirement during Stage 1, but it is a factor in Stage 2. Category 5.3 defines the *Unit Mass* requirements of the desired train across four separate requirements (TTS5.3.1-4) and here we see again some precise articulation. TTS 5.3.1 states that *a full length unit should weigh less than 401 tonnes* (actual for the 12-car Class 700 is 399.6 tonnes) and TTS 5.3.2 states that the *reduced length unit should weigh less than 267 tonnes* (actual for the 8-car Class 700 is 273.5 tonnes). The other two requirements give figures of 385 tonnes and 256 tonnes, as *desirable* weights for the full and reduced length trains. The full-length 12-car train delivered by Siemens was articulate with one set of requirements, but not the *desirable* stretch target, whereas the 8-car train was inarticulate to either target.

When considering this missed weight target, it is important to reiterate the model developed in Chapter 2. The *realised* train (Class 700) is a *translation* of the earlier *proposition* produced by Siemens and others. It is possible that the earlier proposition of a train achieved the weight targets in 8-car formation, and weight was introduced during the translation process. For example, changes might have been needed during the manufacturing process because different components had to be used for many reasons. Alternatively, it is possible that the earlier proposition of a train also had excess weight in the 8-car formation like the realised train. This point of inarticulation would potentially score fewer points compared to rival Bidders if their proposed trains were lighter. It is possible that the Siemens-led proposition scored higher elsewhere. The bid documents from Siemens and other suppliers are commercially sensitive and so it is not possible to know for sure.

The ITT process defines minimum scores required to progress to Stage 3. The competing propositions of trains have been configured and reconfigured by these stages. All three Bidders, and their respective actor-networks, met the requirements to proceed to the next stage.

6.1.4.3 ITT stage 3 – project deliverability

Stage 3 is effectively focused upon the *translation gap* that exists between propositions, developed in the decision-laboratory, and the realised trains they will become in the future. Bidders are required to describe how they will "convert their Proposals into a fully functional maintained fleet of Units" (Department for Transport, 2008b, p. 38). This is assessed in terms of the Bidders' approach to the *Overall Programme* (40%) and their *Management Plans* (60%). As before, weightings are allocated to sub-categories within each of these larger categories, with supporting documentation provided. The *Business Excellence Model,* referenced in the Accreditation Questionnaire (AQ) as part of the initial OJEU notice, appears again during Stage 3 of the ITT. Bidders are asked to identify the components of their response according to: **R**esults, **A**pproach, **D**eployment, **A**ssessment, and **R**eview (RADAR), which is taken from the EFQM model. Each of these elements is given different weightings by the DfT.

The Department asks Bidders to describe how they will deliver the *Overall Programme* across three milestones defined by the DfT:

- 20% weighting for demonstration of the ability to deliver 152 vehicles by the later of July 2013 or 39 months from Contract Award
- 30% weighting for demonstration of the ability to deliver 452 vehicles by the later of June 2014 or 50 months from Contract Award
- 50% weighting for demonstration of the ability to deliver the full fleet by the later of December 2015 or 68 months from Contract Award.

Bidders are given a list of *Management Plans* that the DfT requires across three categories:

- Project Management Plan
- Engineering Management Plan
- In-Service Management Plan

Within each of these three categories there are sub-categories, which have weightings identified against them for the scoring process.

All three Bidders passed stage 3 and entered the final ITT stage.

6.1.4.4 ITT stage 4 – value assessment

Those bids that reach Stage 4 are expected to be able to meet the aims of the Department for the Thameslink Rolling Stock Programme, because they will have achieved the minimum levels of technical compliance in Stage 1, and demonstrated a high level of technical and commercial competence, and deliverability, in Stages 2 and 3. Therefore, Stage 4 is designed to make a selection, or decision, in favour of the best value proposal with a “value assessment based on whole life and whole industry cost of each Bidder’s Proposal” (Department for Transport, 2008b, p. 40). As discussed earlier, the need to manage whole industry costs was a key reason for DfT’s leadership on this strategic decision.

To support the evaluation, DfT made available to the Bidders a cost model with supporting documentation. This cost model calculates the *costs over 30 years* (Department for Transport, 2008b, p. 40) across categories for train leasing, train maintenance, depot leasing, energy consumption, and costs identified using a modelling tool called VTISM – the Vehicle Track Interaction Strategic Model. The VTISM model is described as a whole life cost model for the Vehicle–Track system and was developed for the Rail Safety and Standards Board (RSSB) and Network Rail (NR), by a combination of Serco, DeltaRail, and the University of Huddersfield. The DfT arranged for VTISM training and a help desk to be provided by RSSB. This would allow Bidders to become more articulate with respect to the VTISM model and for this model to act with the propositions.

Upon receiving the completed cost models from Bidders, the DfT then made some *value adjustments*. This included a *performance adjustment* to reflect the expected reliability of the new trains. Reliability problems would incur delays to the train, and a knock-on effect (reactionary delay) to other trains in the area, which would be significant in a congested area like central London. Each modelled delay minute is given a value of £800 per minute in line with the contractual performance regime that exists in the current railway (loop 5, links and knots: *functional specialisation with contractual integration)*. This performance adjustment represents the Thameslink focus upon high throughput and the need for high reliability of services in congested areas. A modelled lack of reliability will produce a modelled set of delays, and a modelled set of incurred costs for those delays. A further adjustment is made by the DfT to reflect the Bidders' acceptance, or otherwise, of a collection of legal agreements that they will be required to sign. This reflects an *adjustment for risk and liability* between the Bidder and the Department.

Submission of proposals by Bidders during Stage 4 marks the completion of the ITT stage of this strategic decision. The initial publication of the ITT took place in November 2008 with proposals submitted in June 2009. In October 2009, Alstom was deselected from the competition (House of Commons Transport Committee, 2011, p. 48) and informed by the DfT that its bid had been eliminated from the final stage of the contest. Siemens and Bombardier were the final two competitors for consideration as Preferred Bidder. This selection was planned for October 2009, but it did not actually happen until June 2011. Critical *external* events would demonstrate that this decision-laboratory had very porous walls and was clearly part of a wider social world. This also demonstrated the challenge of delimiting and defining boundaries to Actor-Networks.

6.1.5 The strategic decision is delayed by 'external' action

The Global Financial Crisis of 2007-08 had an impact upon markets and countries around the world and contributed to a Eurozone crisis affecting Greece and other countries across Europe. Continuing problems in global financial markets "affected the ability of the bidding consortia, with their supporting banking groups, to raise finance" (National Audit Office, 2014c, p. 27). This produced lengthy delays throughout 2009, and the first half of 2010.

Additionally, 2009 was the last year of the Labour Government's third term in office, with an election called for 6 May 2010. The General Election returned no overall majority for any party. A Coalition Government was formed, involving the Conservative and Liberal Democrat Parties, which would govern for the following five years. Against the backdrop of the Global Financial Crisis, and problems in the Eurozone, the Coalition Government ordered a Spending Review of all infrastructure projects in June 2010. The Thameslink Programme was paused pending a review of costs and scope (National Audit Office, 2014c, p. 29). On 25 November 2010, the Secretary of State for Transport, Philip Hammond, confirmed that the Coalition Government would “fund and deliver the Thameslink programme in its entirety” (Butcher, 2012, p. 3), but with completion of the programme delayed to 2018.

During this time, the DfT and the final two Bidders had continued to interact. Between February 2009 and January 2011, the DfT issued five *Supplementary Instructions* to the Bidders. These acted upon various aspects of the proposals, including re-financing options in response to external factors, possible changes to the throughput of trains, possible depot changes, and more.

The final submission in 2011 “was around 7,000 pages in content” (House of Commons Transport Committee, 2011, p. 63), according to written evidence from Siemens plc. The propositions of trains from Siemens and Bombardier – represented in documents, models, measurements, and calculations – would now be evaluated by the DfT to select a Preferred Bidder.

6.1.6 The selection of a Preferred Bidder in June 2011

Bidders’ Proposals were ranked in order of the Net Present Value (NPV) of their submitted Stage 4 cost model, after risk and value adjustments were made. The Bidder whose Proposal had the lowest NPV of costs was to be ranked first. On 16 June 2011, the Rail Minister, Theresa Villiers, announced (Butcher, 2017, p. 17) that Siemens PLC with Cross London Trains – a consortium comprising of Siemens Project Ventures GmbH, Innisfree Ltd and 3i Infrastructure Plc – had been appointed as the Preferred Bidder to build, own, finance and maintain the new trains. The Minister stated that this would “create around 2,000 new jobs and will provide Thameslink passengers with modern, greener and more reliable trains” (*Railnews*, 2011).

However, the decision caused significant headlines in the national press (loop 4, public representation), as illustrated by an article in The Times (Lehal, 2011) titled

"*Death knell for train industry as Germany wins key contract*." The future of the Derby factory of Canadian-based Bombardier was of particular concern, with talk of job losses, impact upon local supply chains (loop 3, alliances), and wider national interests threatened by the selection of a foreign supplier. In evidence to the House of Commons Transport Committee (2011, p. 73) Unite, the majority union at the Bombardier Transportation site in Derby, stated that the selection of Siemens as Preferred Bidder meant that 1,400 jobs were threatened, all apprenticeships had been stopped, and the future of the plant was at risk. In the same evidence gathering session, Bombardier said that "countries such as France and Germany use [MEAT] to ensure that procurement decisions can safeguard a domestic industrial base in the long-term interests of the country" (House of Commons Transport Committee, 2011, p. 12). However, there was no legal challenge, and Siemens remained the Preferred Bidder.

The winning consortium, led by Siemens, still faced problems. Capital was needed to finance the actions to translate the proposition into a realised train, but in this challenging climate prospective lenders were requesting extra support and guarantees from Siemens AG, the parent company headquartered in Germany. An additional guarantee was provided in mid-2012. Later that year "the Department and Siemens held a workshop with some prospective financiers to explain the programme" (National Audit Office, 2014c, p. 31) so that the Department could be assured that these organisations would provide finance (loop 3, alliances). By early 2013 the Thameslink programme debt financing was oversubscribed. The total financing requirement for Thameslink of £1.8Bn (National Audit Office, 2014c, p. 32) was funded by the European Investment Bank (£425m), Commercial Lenders (£1,188m), and £183m of equity finance from Siemens.

In June 2013, the contract was finalised. Siemens and partners would finance, supply, and maintain the fleet of 115 high-capacity trains – 60 Class 700/0 8-car trains and 55 Class 700/1 12-car trains, a total of 1,140 new carriages. The Department – acting on behalf of the future Train Operator – provided guarantees to the train owner that a franchise operator would enter into contracts to use the trains for 20 years (National Audit Office, 2014c, p. 12).

After so long spent represented on paper, in computer models and spreadsheets, the most articulate proposition of a train would now be translated to become the realised train. This further action is outside of the scope of this research, but it is important to note that this is **a translation and not a replication**. **There are many changes that can take place as the proposed trains move through manufacturing and into operational service.** Even when trains emerge from the factory, they are required to go through various *acceptance processes* with Network Rail to ensure they are safe to operate on the UK network.

6.1.7 The realised trains enter service from February 2016

The first unit was delivered in the Summer of 2015, and entered traffic in spring 2016, with all units accepted into traffic by the summer of 2018. The Class 700 trains are the outcome of a strategic decision that began in April 2008, with the publication by the DfT of the OJEU notice, with a history dating even further back.

At the launch of the OJEU in 2008 the Rail Minister, Tom Harris had described "lighter, greener trains" (Rail Technology Magazine, 2008). The analysis in Table 6.2 (page 181) found that the Class 700 trains are indeed lightweight designs, with the 12-car Class 700/1 lighter than all predecessor Class 319s. The *green* credentials of the train are hard to validate, but the new trains have features, such as regenerative braking, that were not present on older trains. The new trains are also proving to be reliable (Roger Ford, 2019a, p. 36) as measured by Miles per Technical Incident as of November 2019. It is too early to determine if the new trains provide value for money, which will depend upon "the Department and train operators managing the contracts and…assumptions…holding true" (National Audit Office, 2014c, p. 45).

Capacity and high-volume throughput into London was a clear focus for this strategic decision and it has been achieved through a combination of the infrastructure programme and new trains. The new trains, together with improvements to stations and signalling, act collectively to provide more trains per hour, reduced dwell times, and to carry more people with their long formations of eight and 12 carriages and long platforms.

Capacity has been increased, but the new trains have fewer seats per car (Table 6.2, page 181) than their predecessors. A train layout with fewer seats works well on short-distance high frequency stopping services but may not work so well for longer journeys on the Thameslink route, such as between Cambridge and Brighton (a direct journey of more than two hours), or for airline passengers with luggage travelling to Gatwick and Luton airports.

The judgment of success of the trains will take longer to assess and will be revealed through use over time. Usage to date has identified a potential problem. Complaints have been “rising about the seating comfort…[with] bone hard fabric seats with poor legroom" (RAIL Opinion, 2017, p. 57). The phrase “ironing board seats” (Graeme Paton, 2018) has been used in the national papers and elsewhere (loop 4, public representation). This apparent problem with comfort is despite the Thameslink ITT specifically requiring (TTS 8.4.1) that the *Unit ride quality shall achieve a mean comfort index of 2 based on the ENV 12299:1999 Ride Comfort for Passengers, Measurement and Evaluation.* It is possible that the proposition of a train from Siemens did not achieve this index of 2, because this was not a mandatory requirement. If this was the case, then the proposition of a train had less comfortable seats than desired and this could have been translated into less comfortable seats in the realised train. We cannot say, however we do know that comfort has surfaced as a problem in their actual use. Some of the response to this criticism pointed to the need to meet fire and anti-graffiti standards, which might give a firmer feel. However, the Rail Safety and Standards Board (RSSB) did not accept this explanation and commissioned research (RSSB, 2019) to improve the specification of comfortable seats, building upon earlier work to measure (loop 1, mobilisation of the world) rolling stock comfort (RSSB, 2016).

One thing we cannot know is how the alternative propositions of trains, created by Bombardier and Alstom, would have performed if they were translated into realised trains. Bombardier based their proposal around their *Aventra* train model. They also included a consortium of partners, branded as *VeloCity,* to help provide the whole of this action – the financing, depots, and maintenance. Alstom had proposed a train based on its *X'Trapolis* design. Unlike the other two proposals with 12-car formations, the Alstom proposal was a train in a 15-car formation, with two doors per car, potentially supporting faster loading and unloading of passengers from a cumulative 30 doors per train, compared to 24 for the Siemens Class 700. Both alternative propositions remain unknown in practice – they remained in propositional form.

Ultimately it was the Siemens consortium, based on the *Desiro City* model, that was translated into the Thameslink Class 700. We know how that has performed to-date, and its actual performance can continue to be monitored and evaluated.

This section has used ANT to understand how the propositions of trains were articulated and shaped within the Thameslink decision-laboratory. A diverse collection of resources come together to act upon the propositions being articulated. The five circulating loops were used to explore the activities taking place within this decision-laboratory to produce propositions of new trains. This next section applies the same approach but with a different strategic decision – the selection of new trains for the Crossrail network. The Crossrail Class 345 trains are suburban EMUs, like Thameslink Class 700s, that provide commuter services in and around London. The Class 345s have also been recognised for their lightweight designs. The following analysis will investigate how they were articulated within the Crossrail decision-laboratory. At the end of this chapter there will be a summary to review the lessons from both Thameslink and Crossrail.

6.2 Crossrail and the Class 345s

Crossrail is the project name for a large railway programme to join the mainline railways to the east and west of London, through the construction of two tunnels beneath central London, from Paddington to Liverpool Street. The completed project will allow Crossrail services to operate between Reading, in the west, and Shenfield and Abbey Wood, to the east of London, as well as providing links from central London to Heathrow Airport. A map of Crossrail is shown below in Figure 6.9.

Figure 6.9 Crossrail route map

When complete, the railway will be around 74 miles (118km) long (Reading to Shenfield), with around 13 miles of new tunnels under central London. There are 10 new stations being built as part of the Crossrail programme, and a further 31 are being improved. Once Crossrail is open, it will become part of Transport for London's (TfL) rail and underground network and it will be known as the Elizabeth line. As part of this wider programme, a fleet of new trains were to be ordered to operate on the new railway and provide a high frequency, high-capacity service linking 41 stations. The *western section* of the Elizabeth line route will run on the existing rail network from Paddington to Heathrow and Reading. The *central section* will run from Paddington to Whitechapel in the east, with a branch to Abbey Wood in the south-east. There will be up to 24 services per hour during the peak in the central section. The *eastern section* of the Elizabeth line route runs on the existing rail network between Stratford and Shenfield in Essex.

A summary of the dates and key events in the Crossrail Rolling Stock procurement are shown in Table 6.4 below. This table provides an overview before the subsequent detailed analysis.

Table 6.4 Key events in Crossrail rolling stock procurement

Year	Event
2010	• Government spending review agrees £14.8Bn funding package (excluding trains and depot) for Crossrail programme • November 2010: Issue of pre-qualification OJEU notice for supply of Crossrail rolling stock and depot facilities
2011	• 30 March 2011: Crossrail invites five companies to tender: Alstom; Bombardier; CAF SA; Hitachi Rail; and Siemens • August 2011: delay following award of Thameslink (June 2011) to Siemens and Government review of public procurement practices • 30 August 2011: Alstom withdraws
2012	• 28 February 2012: Crossrail issues Invitation To Negotiate to remaining four Bidders • November 2012: First-round bids received from Bombardier, CAF of Spain, Hitachi, and Siemens
2013	• March 2013: Government announce change to financing approach • July 2013: Siemens withdraws citing Thameslink commitments • August 2013: Revised bids from Bombardier, CAF, and Hitachi
2014	• February 2014: TfL awards contract to design, build and maintain the trains for Elizabeth line (including a maintenance depot) to Bombardier Transportation.
2017	• 22 June 2017: first train enters service between Shenfield and Liverpool Street in 7-car (not 9-car) formation

6.2.1 The realised trains: the outcome of the strategic decision

The new Class 345 trains replace services that were previously operated by Class 315 and Class 360 trains. There are five Class 360/2 trains, that operate between London Paddington and Heathrow, that are replaced by the new Class 345s and 49

Class 315 units that operate other parts of the network. The Class 315s were first introduced into service in 1980 and are expected to be scrapped when all Class 345 trains are finally introduced. To provide a comparison between old and new some pictures of the exterior and interior of the Class 345 and Class 315 trains are shown below. A visual representation (Figure 6.14) of the Class 345 and Class 315 shows how each car contributes to each trains’ total length, number of seats, and weight.

Figure 6.10 Crossrail Class 345 built by Bombardier

Source: Crossrail website

Figure 6.11 Seating for Crossrail Class 345 built by Bombardier

Source: Crossrail website

Figure 6.12 Class 315 replaced by Class 345 on Crossrail

Source:(Marsden, 2011, p. 176)

Figure 6.13 Class 315 typical seating of 3+2

Source:(Marsden, 2011, p. 177)

Figure 6.14 Weight and seat profile for Class 345 9-car EMU (top) and Class 315 4-car EMU (bottom)

Weight (t)	**318.4**	**39**	**37.1**	**36.5**	**31.4**	**29.7**	**31.4**	**37.2**	**37.1**	**39**
Seats	**454**	**46**	**52**	**52**	**52**	**50**	**52**	**52**	**52**	**46**
Length	**204.7m**	**23.62m**	**22.5m**	**22.5m**	**22.5m**	**22.5m**	**22.5m**	**22.5m**	**22.5m**	**23.62m**

Weight (t)	**137.6**	**38.2**	**27.4**	**33.8**	**38.2**
Seats	**316**	**74**	**86**	**82**	**74**
Length	**80.7m**	**20.18m**	**20.18m**	**20.18m**	**20.18m**

Using the same format as the original chart that prompted this research (Figure 1.5) the Class 345 EMUs for Crossrail, and the trains that they replace, are shown in Figure 6.15 below.

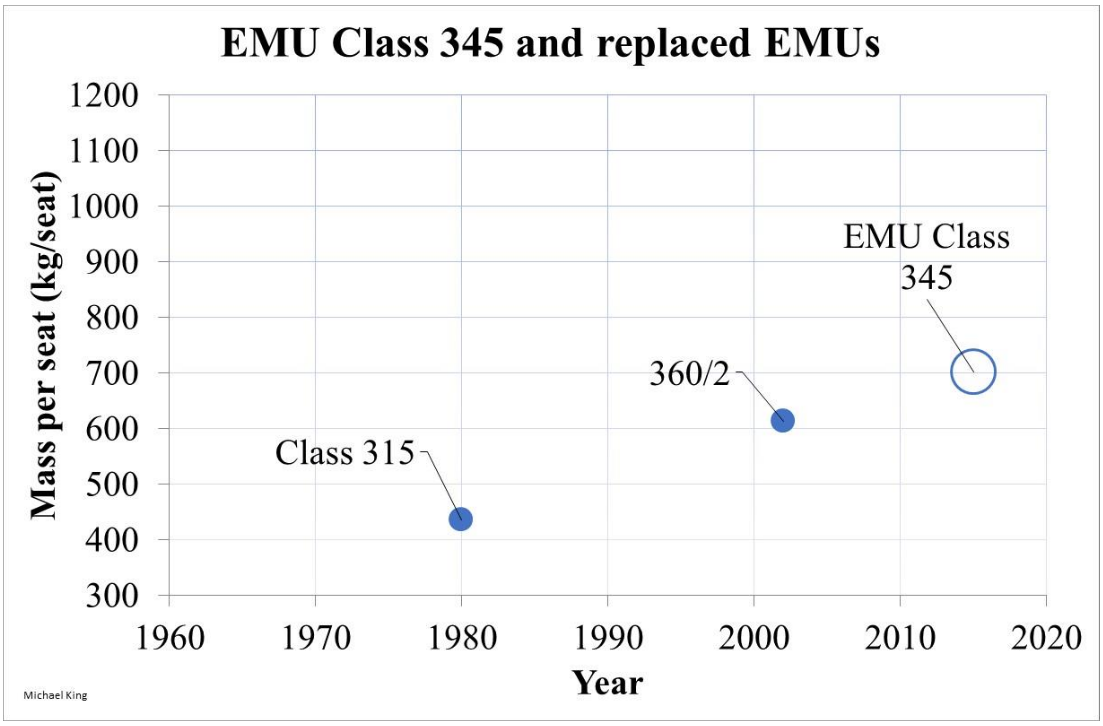


Figure 6.15 Class 345 EMUs and the trains they replaced (kg/seat and year of introduction)

A visual inspection of Figure 6.15 shows that the Class 345 trains are heavier per seat than the units they are replacing. Table 6.5 below contains the information for the Class 345, Class 315 and Class 360/2 trains that was used to make the chart.

Table 6.5 Weight and seat data for Crossrail Class 345 and the Class 315s and 360/2s they replace

	Cars per trainset	Seats per trainset	Weight of trainset	Average car weight (tonnes)	Seats per car	Weight per seat (kg/seat)
345	9	454	318.4	35.4	50.4	**701.3**
315	4	316	137.6	34.4	79.0	**435.4**
360/2	5	331	202.8	40.6	66.2	**612.7**

This table shows that the new Class 345s are heavier per seat than the Class 315s and Class 360/2 that they replace. The 9-car Class 345 has 454 seats and weighs 318.4 tonnes in total, giving a figure of 701.3 kg/seat. However, the Class 315 is the lightest per seat in this table. It is a 4-car unit with 316 seats and weighs 137.6 tonnes, giving a figure of 435.4 kg/seat. To investigate this further, like in Chapter 4, we can break the metric of weight per seat into its component parts.

Table 6.5 shows the average weight of a car for the 9-car Class 345 is 35.4 tonnes per car, which is heavier than the Class 315s that weigh 34.4 tonnes per car, but lighter than the Class 360/2 at 40.6 tonnes per car. However, the Class 345 carriages are 23 metres long, whereas the Class 315 and 360 are 20 metres long (see Figure 6.14 on page 218). The Class 345 has more usable space onboard for passengers and facilities, but this would be expected to increase weight.

A significant difference is visible in the number of seats, with an average of 79 seats per car for the Class 315s, compared to 50 seats per car for the new Class 345s. An explanation for this difference is that the Class 345 trains feature a mix of longitudinal and bay seating in 2+2 layout (Figure 6.11), whereas the Class 315s use a 3+2 seating format, as shown in Figure 6.13 above. The Class 345s have space devoted to standing passengers with hanging straps and grab rails.

The new Class 345 trains are a lightweight design, which is impressive considering their longer carriages. Their hybrid seating and standing configuration means that they have fewer seats per car than their predecessors.

The next section explores the Crossrail procurement where propositions of trains were articulated, and one was selected to become the realised train described above.

6.2.2 Activities before the procurement

Like Thameslink, the starting point of this strategic decision to produce new trains for Crossrail has a long history. Early work started in the 1970s, under British Rail, to investigate opportunities to relieve congestion around London and the South East to cope with expected future growth. However, feasibility studies in 1974 and 1980 (National Audit Office, 2019, p. 8) concluded that it would be too costly.

The project was picked up again in December 1999 when John Prescott, the Deputy Prime Minister, asked the Strategic Rail Authority (SRA) to review east-west travel across London. The resulting report (Shadow Strategic Rail Authority, 2000) recommended new rail links across London to relieve existing, and forecast, overcrowding and congestion. In 2002, Cross London Rail Links (which became Crossrail Ltd in 2009) was formed by Transport for London (TfL) and the SRA. TfL is the local government body responsible for the Greater London transport system, including roads, trams, buses, taxis, cycling and aspects of railway services, such as London Underground When the SRA was abolished in 2005, the Department for Transport (DfT) took on the SRA’s role and acted as joint sponsor, together with TfL.

The Crossrail programme was re-assessed (Crossrail Ltd, 2005). Forecasted growth to the population in London and the South East was expected to produce increased demand for public transport. The Crossrail Elizabeth line was estimated to provide a 10% increase in rail capacity in central London. The benefits of Crossrail included “reduced journey times, reduced crowding on public transport and quicker interchanges between services” (National Audit Office, 2014a, p. 5). These benefits were mobilised (loop 1, mobilisation of the world) to strengthen the Crossrail programme. Benefits were calculated to exceed costs (Haylen, 2019, p. 19) and so, both the Department and Transport for London decided to invest and progress the project. Legislation required to build the railway gained Royal Assent in 2008 (Her Majesty’s Government, 2008). Cross London Rail Links was renamed Crossrail Ltd in 2009. It is a wholly owned subsidiary of TfL and is responsible for delivering the Crossrail programme. Network Rail were responsible for work to improve existing rail infrastructure. Construction started in 2009 on the first Crossrail site, Canary Wharf station.

The General Election of 6 May 2010 produced a Coalition Government which, against the backdrop of the Global Financial Crisis and problems in the Eurozone, paused infrastructure projects subject to a Comprehensive Spending Review in June 2010. Overall funding for Crossrail was reduced by £1 billion to £14.8bn. This funding was provided (National Audit Office, 2014a, p. 5) by a network of alliances (loop 3, alliances) including direct grant funding from DfT and TfL, borrowing by Network Rail and Transport for London, and contributions from businesses, including a supplement to London business rates. The funding only covered the construction costs of the railway. An estimated £1 billion additional cost (National

Audit Office, 2014a, p. 9) was needed to buy the trains. The majority of this was funded directly by Transport for London, with DfT providing £100 million.

As with Thameslink, the detailed analysis of the production of new trains will start with the OJEU notice of the procurement, which was published by Transport for London and Crossrail Ltd in November 2010.

6.2.3 Early actor-network development: the OJEU is issued in November 2010

An OJEU Contract Notice (2010/S 233-356965) was issued 26 November 2010 and requested expressions of interest by February 2011. The first thing to highlight on the OJEU notice (Appendix, page 369) is that the address for the contracting entity is Transport for London c/o (care of) Crossrail Ltd. Although DfT are a joint sponsor, there is no mention of them in the OJEU notice. This reflects the fact that Crossrail Limited was established as the company to build the new Crossrail railway that will become known as the Elizabeth line. Crossrail Limited is the “delivery body” (National Audit Office, 2014a, p. 10) and it is a wholly owned subsidiary of Transport for London (TfL). Once the railway is complete, it will be run by TfL as part of London’s integrated transport network. To help understand early actor-network formation we can define Crossrail Ltd here as *Prime Mover*. Crossrail, the institution, is shaping the early network and allocating roles to actors expressing an interest in response to the notice that they have published.

The OJEU notice does not give much information on the background to this procurement. The initial *problematisation* (Callon, 1984, p. 6) – definition of the problem to be addressed by the actor-network – is provided by a mix of high-level information and some specific direction. The trains are to be 200 metres long, although early services will need to operate as 160m-long trains. Their design life should be 35 years with high levels of reliability and performance, and able to support 24 trains per hour in the central section. The trains must integrate with the local technical infrastructure. A future member of the network is described in the OJEU, because the supplier of trains will be expected to work with a *Crossrail Train Operating Company* that is expected to be in place as the services go live. The scope of work also includes the design and construction of a depot and maintenance services for the new trains. Financing for each part of the scope is a requirement, although there are options for Crossrail to change their approach. The cost for this package of requirements is estimated to be between £1bn and £1.9bn.

The final point to note regarding the OJEU notice relates to the stated *award criteria*, which is defined as the *most economically advantageous tender in terms of the criteria stated in the specifications or in the invitation to tender or to negotiate*. This is the same as the Thameslink procurement, and reflects EU law where a procurement can be based on price alone, or on the broader basis of the 'most economically advantageous tender' (MEAT) (House of Commons Transport Committee, 2011, p. 12). The definition of MEAT will be developed as the procurement process unfolds.

The OJEU directs interested parties to download a Pre-Qualification Pack, which must be returned by the deadline of 24 January 2011. The Pre-Qualification Pack was obtained from Crossrail via a Freedom of Information request (Appendix, page 366). Included is a Pre-Qualification Questionnaire (PQQ) which aims *to assess Applicants against the characteristics which CRL [Crossrail] has identified as being important for the successful tendering and delivery of the Project Services*. The PQQ is clear throughout that it is CRL (Crossrail) seeking answers and looking for evidence from interested parties. Trading and financial information must be provided for the lead organisation and any members of a consortium. This document provides Crossrail a way to engage respondents in a process of *interessement* (Callon, 1984, p. 8). Crossrail, as Prime Mover, are allocating roles to interested parties and create associations across the developing actor-network that will produce propositions of new trains. The scoring system for the PQQ, with areas and weightings, is shown in Table 6.6 below.

Table 6.6 Structure of the Crossrail Pre-qualification Questionnaire with weightings for scoring system

PQQ Areas	Weighting
Section C1 - Health and Safety	5%
Section C2 - Quality and Assurance	3%
Section C3 - Environment	2%
Section D - Corporate Social Responsibility and Customer Relationships	5%
Section E - Ability to design and build trains	30%
Section F - Ability to design and build the depot	17.5%
Section G - Ability to maintain trains and support operational requirements	27.5%
Section H - Ability to arrange and provide finance	10%
Total	**100%**

How these figures have been allocated is not explained, but the structure aligns with that set out in the OJEU. The sections that attract the most points are those that relate to the *ability to design and build trains* (Section E, 30%) and to the ability to *maintain trains and support operational requirements* (Section G, 27.5%). For Crossrail, propositions of trains are also articulated with the building of a depot (17.5% weighting) and financing (10% weighting) as part of the collective action.

This document acts to create relationships and associations among actors. For example, a sub-category (E 6) assesses the Respondents' ability to manage *compliance*, *testing*, *commissioning, and customer acceptance*. This will involve Network Rail *accepting* the trains onto UK rail infrastructure.

Seats are not mentioned explicitly anywhere in the PQQ. However, the weight of the trains is referenced within Section E. Recognising that Bidders will bring their existing propositions of trains to this action the PQQ asks them to *demonstrate an* *ability to adapt existing designs to meet the Crossrail specification requirements including…*

- *delivering an efficient* **mass to passenger capacity ratio** [emphasis added] *to reduce energy and track maintenance costs*
- *optimising whole life costs (including energy efficiency) while meeting performance requirements*

Mass to passenger capacity is a similar metric to kg per seat, although it could include standing room capacity and not just seats. The emerging actor-network needs to consider the weight and energy usage of the trains that will be produced, but there are no specific targets or numbers provided at this stage.

Potential trade-offs between *whole life costs* and *performance requirements* are recognised, which reflects timetable requirements for 24 trains per hour in the central section. This implies short dwell times at stations with trains arriving and departing every 2-3 minutes. Achieving this requires a range of attributes of the trains, including fast acceleration and braking, which could lead to greater energy usage. The PQQ directs Bidders to optimise whole life costs if there are trade-offs to be made. The design life of the train is not stated in the PQQ, but the OJEU had given it as 35 years.

This PQQ forms part of a wider discourse, which also includes presentations, industry briefings, Q&A, and various discussions inside the railway industry and related sectors. This early stage of network formation is mostly formed from within the railway professions (loop 2, autonomization), but the high-profile nature of the Crossrail programme places this within the public eye, given its large economic costs and visible impact upon the London geography.

Responses to the PQQ were required by 24 January 2011, according to the OJEU, and, in March 2011, Crossrail confirmed that five organisations would be invited to tender: Alstom Transport; Bombardier Transportation (UK) Ltd.; Construcciones y Auxiliar de Ferrocarriles SA; Hitachi Rail Europe Limited; and Siemens plc. Crossrail stated that detailed requirements for the new trains were being finalised and the intention was to put out an Invitation to Negotiate (ITN) and invite these five companies to submit bids in 2011, with a view to awarding a contract to build the Crossrail fleet in late 2013.

6.2.4 Increasing articulation of propositions: the ITN is issued in March 2011

This ITN stage represents the development of more articulate propositions and it was to involve two rounds. In the first-round, Bidders would provide technical proposals and their approach to securing the necessary finance. Shortlisted bidders were then to be invited to provide fully funded proposals in the second round, with a preferred bidder selected at the end.

Crossrail provided further technical aspects of the desired trains (appendix D, page 375) and required attributes, such as the maximum length (205 metres), power supply (25 kV AC from the overhead line), and so on. This document included an explicit weight target, with the new train to be **less than 350 tonnes**. Energy-saving features, including regenerative braking, were detailed, as was a desired energy efficiency of 24 KWh per train kilometre, which it says is equivalent to 55g CO2 per passenger kilometre.

However, in June 2011 it was announced that Siemens had been made preferred supplier for the Thameslink contract, with the new trains to be built in Germany. As discussed earlier in this chapter, Bombardier had lost out and subsequently announced job losses, including a review of the future of its Derby plant. Unite the union said that it was “not just the jobs at Bombardier placed at risk, but also those in the region’s supply chain” (House of Commons Transport Committee, 2011, p. 74 Ev 48). A political debate about UK public sector procurement ensued, and Crossrail announced that the issuing of tender documents was to be deferred. The difficulty of defining the edges of an actor-network were demonstrated, as the *separate* Thameslink strategic decision acted upon Crossrail.

6.2.5 Public sector procurement practices come under scrutiny in June 2011

Upon coming to power in 2010 the Coalition Government created a National Infrastructure Plan. The annual review of this plan, in 2011, reviewed issues associated with public procurement practices. A Crossrail press release described this review as “examining…the degree to which the Government can set out requirements and evaluation criteria with a sharper focus on the UK’s strategic interest” (Peter MacLennan, 2011). To allow the findings to be factored into the Crossrail procurement, the date for the planned award of the contract was pushed back from 2013 to 2014.

In August 2011 it was announced (Milmo, 2011) that Alstom, the French manufacturer of the Pendolino trains operating on the West Coast of England, was to withdraw from the Crossrail tender process. Alstom stated that “it lacked a suitable product for the work” (Robert Wright and Helen Warrell, 2011) and that adaptation of their existing products was not compatible with Alstom’s strategy and Crossrail’s requirements.

The National Infrastructure Plan stated that “the UK’s transparent and fair approach to public procurement is viewed positively by inward investors” (HM Treasury, 2011a, p. 112). However, the Plan identified opportunities for improvements to procurement practices to “support a consistent approach to the consideration and appraisal of infrastructure projects across Government” (HM Treasury, 2011a, p. 92). Supplementary guidance was issued for the Treasury’s *Green Book* (HM Treasury, 2018), which is the central Government framework for appraisal and evaluation of policies, programmes and projects. This guidance recognised the challenges of assessing costs and benefits for infrastructure spending. This was illustrated with an example of a railway line, which provided direct benefits to passengers through faster journey times, reduced over-crowding and a more pleasant journey. Additional benefits beyond this could include reduced road congestion, which could lead to reduced CO2, improved air quality and less noise pollution. The supplementary guidance to the Green Book went on to suggest (HM Treasury, 2011b, p. 9) that the “new rail line may also have a positive effect on economic activity in deprived areas served, potentially bringing a combination of regeneration benefits and new employment opportunities.” This is a recognition of the wider actor-network involved in the production of new trains, with this action reaching out to form alliances (loop 3) and connect with a wider public (loop 4) beyond the immediate railway industry. The revised Green Book approach states that costs and benefits should be quantified and monetised where possible, and still included in the analysis where this is not possible.

In November 2011 the intention to “continue to implement the £14.5 billion Crossrail project” (HM Treasury, 2011a, p. 47) was announced. The updated National Infrastructure Plan from the Treasury had acted and would be incorporated into the revised Crossrail action.

6.2.6 The ITN resumes in 2012 with a requirement for responsible procurement

On 28 February 2012, the Secretary of State for Transport published a Written Ministerial Statement outlining how recommendations from the procurement review were reflected in the Crossrail rolling stock and depot procurement. The Invitation to Negotiate (ITN) included requirements for *responsible procurement*. Bidders were required to describe "how they will engage with the wider supply chain and provide opportunities for training, apprenticeships, and small and medium-sized businesses…to establish an appropriate local presence to manage the delivery of the contract…[and] to specify from where each element of the contract will be sourced" (Greening, 2012). A wider actor-network was explicitly recognised in this strategic decision.

The award of Thameslink to Siemens had acted upon the revised procurement guidelines, but it was also claimed that Siemens now held an advantage in the Crossrail procurement because of "clear similarities" (Milmo, 2012) between the two railways. The head of Siemens' UK train division denied this and stated that he expected the Crossrail process to be handled "in a fair manner that offers a level playing field to all bidders, regardless of nationality" (Milmo, 2012). Under EU rules, the government cannot prefer a domestic company, and the Ministerial statement clarified that this was "not an assessment criterion in the decision process" (Greening, 2012). However, bidders were required to provide estimates for local sourcing, and these estimates would be monitored subsequently.

A new concept of how trains are produced (loop 5, links and knots) has emerged. This new concept places greater emphasis upon the wider social and economic value associated with the translation of propositions into realised trains. This has parallels with the early days of the railway (see section 5.1) when the railways were not just a provider of transportation services. They were also a significant construction enterprise, provider of employment, and creator of opportunities (loop 3, alliances and loop 4, public representation).

Alstom had withdrawn earlier in August 2011. The remaining four bidders (Bombardier, CAF, Hitachi, Siemens) were issued with revised tender documents in February 2012. In November 2012 the Transport Minister, Norman Baker, indicated

(Butcher, 2017, p. 18) that the four bidders had submitted first-round proposals by the deadline of 29 October. The submitted proposals described the technical characteristics of the propositions of trains, as well as how each Bidder would secure finance to manufacture and deliver the realised trains. However, the financial aspect of this strategic decision was coming under scrutiny.

6.2.7 Financing is reconfigured in early 2013

As discussed above, the Department and TfL had originally agreed (National Audit Office, 2014a, p. 26) that the trains and their maintenance depot should be funded through a Private Finance Initiative (PFI) deal, with private sector companies arranging finance. However, the Global Financial Crisis and Eurozone problems had impacted the availability of private finance. Even as the Global Financial Crisis began to recede, changed lending rules led to a reduction in long-term lending for infrastructure. In response to this the Chancellor, George Osborne, launched the UK Guarantees scheme in July 2012. The Crossrail trains were a candidate for this scheme and, in September 2012, the Chief Secretary to the Treasury, Danny Alexander, announced that the Government, which was already providing 30 per cent of the funding for rolling stock, was “prepared to guarantee the remainder, which will be financed as a private finance initiative” (Jim Pickard and Mark Odell, 2012).

In late 2012, TfL expressed concerns that private financing could delay the programme, citing recent transport PFI deals such as the Thameslink programme, which was delayed by over three years. Transport for London now proposed to buy the trains and depot directly. Assessments of the value for money of PFI and 100 per cent public procurement were re-visited. Transport for London’s analysis found in favour of public procurement, whereas the Department for Transport’s (co-sponsor) analysis (National Audit Office, 2014a, p. 26) was in favour of PFI. Each of these analyses are mobilising evidence from the world (loop 1, mobilisation of the world) to support their case. However, the difference between each organisation’s assessment was marginal.

By 2013, market conditions had improved and “lending to UK infrastructure projects had returned to 2006 levels” (National Audit Office, 2015, p. 7). Private financing was again a viable option that did not require the UK Guarantee scheme. However, in February 2013, following discussions between Transport for London, HM Treasury, and the DfT, the sponsors agreed to abandon the PFI approach. In effect, the Government agreed to the Mayor of London's (Boris Johnson) proposal to move from a financing model involving a substantial element of private sector funding, to one entirely funded by the public sector. On 1 March 2013 the Transport Minister, Stephen Hammond, announced "a change in the financing approach for the Crossrail rolling stock and associated depot facilities contract" (Butcher, 2017, p. 19).

The concept of how to produce new trains (loop 5, links and knots) had changed again. A changing concept produced a reconfiguration of the actor-network. Financing was still necessary in this strategic decision, but it had moved from privately sourced finance to public.

6.2.8 The ITN is reissued in April 2013

An updated ITN (Invitation to Negotiate) was issued in April 2013, with a deadline for proposals of 29 July 2013.

In July 2013 Siemens announced it was withdrawing from the process. The German company insisted this was not a result of political pressure, and said it had no complaints about the bid process, which had been "fair and diligent" (Rankin, 2013). However, the reconfigured concept of trains with public financing and local sourcing may have impacted the advantages of their actor-network to produce new trains relative to the actor-networks of their rival Bidders. An earlier House of Commons Transport Committee review of the Thameslink procurement had stated that it was "hard to escape the conclusion that Siemens' A+ credit rating made a significant contribution to its success" (House of Commons Transport Committee, 2011, p. 3).

The remaining Bidders received the ITN documentation and the articulation of propositions recommenced. A long list of stakeholders involved in this action was provided to Bidders:

1. TfL and the Secretary of State for Transport (Sponsors of the Crossrail Project)
2. Crossrail Limited (responsible to the Sponsors for delivering Crossrail)
3. Network Rail; Canary Wharf Group and Berkeley Homes (industry partners in the construction of Crossrail infrastructure)

4. Crossrail and the industry partners' contractors and subcontractors engaged in delivering the Crossrail infrastructure and associated services
5. Heathrow Airport Limited and Network Rail (owners of infrastructure over which Crossrail services will operate)
6. Rail for London (subsidiary of TfL) as manager of infrastructure in the Central Section of the Crossrail Project
7. Network Rail (manager of part of the infrastructure over which Crossrail Services will operate)
8. various statutory bodies (approvers of the trains, depot, and railway operations)
9. various public and private bodies who may be affected by the Works and / or the Services
10. Crossrail Train Operating Company (the operator of the trains and user of the depot)
11. London Underground, Network Rail and various train operating companies (users of the infrastructure or operators of stations on the Crossrail route)
12. neighbours of the new depot; and
13. members of the public (users of Crossrail Services)

This list recognises a range of actors, including railway institutions (loop 2, autonomization), partners who will benefit from the services, such as Heathrow (loop 3, alliances), and neighbours and users of the Crossrail services (loop 4, public representation). Bidders were not allowed to contact stakeholders regarding the proposal, unless approved by Crossrail.

The ITN reconfirms that this action to produce new trains also included the building of a depot, and the provision of maintenance and other services. This is to be provided by the selected Bidder for 32 years from the start of the contract. This collective – trains, depot, and services – will *become*, with the wider Crossrail programme, the Crossrail railway service operating in and around London. The ITN describes Crossrail's requirements for the desired trains, depot, and services; however, it is only the requirements for the trains that will be explored in detail here.

The ITN states that a minimum fleet of 60 new trains are required. This is an increased level of specificity over the OJEU and PQQ, which had described a desired level of future operational service required from a fleet of unstated size. Desired features (attributes) of the trains are provided (appendix D, page 375). The trains must have a hybrid nature that allows them to accommodate large numbers of passengers for metro style operations in the central section, but also provide a comfortable environment for longer journeys. The high throughput in the central section (24 trains per hour) requires rapid movement of passengers on and off the train, so dwell times at stations must be minimised. The train's acceleration and braking performance must also support the rapid transportation of large volumes of people. Integration with lineside signalling systems is critical to regulate access of all services, especially in the busy central section. A collective effort is required to deliver the high throughput in the central section.

Crossrail has created a Train Technical Specification (TTS) to ***embody*** [emphasis added] *those technical features considered necessary to deliver the Sponsors' requirements for the Crossrail Project*. The TTS was used by Crossrail to evaluate propositions and so competing Bidders will need to *articulate* their propositions with the attributes and characteristics embodied in the TTS. A similar technical specification was created for the Depot works, but this will not be explored here.

The TTS has **more than 750 unique identifiers** describing desired characteristics of the propositions of trains. Some examples are shown below:

- TTS 3.2.1.4: The Unit shall be able to achieve and maintain a maximum operating speed of 145kph on tangent level track **in open air whilst travelling into a headwind of 50kph** [emphasis added], and at all loading conditions up to and including Normal Payload while operating on traction power supplies of 24kV.
- TTS 3.9.1.2: The Unit shall ensure the Mean Comfort Index shall not exceed 1.9 when operating on any section of the Crossrail Infrastructure…For each measurement location within the saloon the Mean Comfort Index shall be **calculated by taking the arithmetic mean of all comfort indices** [emphasis added] calculated for that location.
- TTS 3.13.1.12: When regenerating the maximum current returned to the AC network by the Unit shall not exceed 300A.
- TTS 3.26.1.2: Inter-vehicle gangways shall be as wide as practicable, having sufficient width to **allow at least two 95th percentile adult UK male passengers to pass each other** [emphasis added] line abreast unimpeded.

- TTS 3.40.3.1: The driver's cab shall be provided with the following facilities: **two coat hooks** [emphasis added]; small waste bin; two cup holders…and two BS1363 type socket outlets…
- TTS 3.34.4.4: **Toilet facilities shall not be fitted within the Units**…
- TTS 3.47.1.1: The Unit shall have a **design life of 35 years** based on the service specifications outlined…

These examples illustrate the high level of specificity (e.g., two coat hooks, 300A maximum current returned by regenerative braking) regarding the desired future train. The train will not include toilets, which reflects its metro-style service like London Underground trains. Gangways between carriages, that allow congestion to be eased as the trains are moving, must be the width of two 95th percentile adult UK male passengers. Here, adult UK males are brought into this action (loop 1, mobilisation of the world) in the form of statistics. Train comfort is mobilised through the uses of a *Mean Comfort Index*, which Bidders are required to use to measure and articulate their propositions. The TTS acts with propositions of trains under development in the decision-laboratory. Propositions become more articulate through this action.

Crossrail will also assess Bidders' ability to deliver – to *translate* their propositions of trains into realised trains. This assessment of *deliverability* was also assessed during the earlier PQQ stage. For example, Bidders' approaches to Health and Safety, Quality and Environment were all assessed at the PQQ and are further assessed during the ITN. One important point to note is that *the ability to arrange and provide finance* that was assessed during the PQQ stage (weighting of 10% in the total score) **is no longer assessed for the ITN**. The changed concept of how trains are produced (loop 5, links and knots) has reconfigured the actor-networks producing propositions. Financing is still part of the actor-network to produce new trains, but it is now being provided by TfL rather than private finance institutions. TfL are arranging loans, with finance institutions, to buy the trains outright from the winner, rather than the Bidder owning the realised trains and leasing them to TfL.

The evaluation criteria defined in the TTS and other parts of the ITN are applied by Crossrail at each stage leading up to Contract Award. The four stages to evaluate the competing propositions are:

Stage 1 – General Review and Mandatory Requirements

Stage 2 – Technical and Deliverability Evaluation

Stage 3 – Commercial Evaluation and negotiations

Stage 4 – Contract Award

6.2.8.1 ITN stage 1 – general review and mandatory requirements

This first stage involves a general review of the proposals from Bidders and assessment against a sub-set of mandatory requirements. A mandatory set of 27 requirements are identified from more than 750 separate requirements in the Train Technical Specification (TTS). Mandated aspects of the depot proposal are also described in the ITN, but they will not be explored here.

The mandated requirements state that the fleet size must consist of a minimum of 60 full length units. The length of the train is mandated, with a *Full Length Unit* required to be no longer than 205 metres, and a *Reduced Length Unit* no more than 163 metres. Station platforms act upon the length of the trains because of the material relationship between train and infrastructure.

A specific weight target for the trains is mandated: **A Full Length Unit is not to exceed 350 tonnes (TTS 3.5.1.1).** The actual weight of the realised trains – the 9-car Class 345s – subsequently delivered by Bombardier was 318.4 tonnes. Without access to Bombardier's proposal, we do not know the exact weight of the proposition that preceded the Class 345. However, we do know that it must have been less than the mandated maximum weight of 350 tonnes, or it should not have progressed.

The number of seats is not mandated, but total capacity (seated and standing) is required to be **a minimum of 1500 passengers** (TTS 3.34.3.2). The actual Class 345 realised trains have a total capacity of 1,500 that includes 454 seats. This reflects the mixed use of these trains as metro operations in central London, while also providing services to regions outside of the city. The Class 345 realised trains are articulate with the hybrid requirements for seating and standing. They have some 2+2 seating for longer distances, but mostly longitudinal seating, like London Underground, to give maximum floor space. The internal picture shown earlier (Figure 6.11, page 215) illustrates this layout. The ITN states that the number of standing passengers that can be carried must be calculated using a density of no more than four persons per square metre. The realised trains may carry more, or less, than four standing persons per m2, but the propositions of trains cannot.

6.2.8.2 ITN stage 2 - technical and deliverability evaluation

Proposals which pass stage 1 are next evaluated across a range of technical and deliverability criteria. The technical criteria include two main sub-categories that further demonstrate the articulation of trains with their depots.

a) Technical criteria

- Train Works
- Depot Works

The technical criteria for the depot works will not be explored here. The Train Works criteria are provided in the appendix of this document (appendix D, page 378). Within Train Works there are 13 sub-criteria that articulate attributes of the desired trains and are used to assess the competing propositions of trains created in this decision-laboratory. Each of these sub-criteria are associated with different *clauses* from the TTS. For example, *Physical Behaviour* is one of 13 sub-*criteria* to assess the proposed Train Works. This is shown in Figure 6.16 below and will be discussed further to show how this articulates the propositions of trains being configured.

Sub-criteria	**Relevant requirements, components and weightings** (Clause references relate to the Train Technical Specification and are deemed to include other requirements cross referenced in the relevant clauses)		
Physical Behaviour (10%)	Clause	Component	% of score
	3.7	Gauging, Routes and Stepping Distance	25%
	3.8	Track Wear and T-Gamma	35%
	3.9	Ride & Stability	10%
	3.10	Noise and Vibration	20%
	3.23	Lubrication	10%

Figure 6.16 Crossrail Train Works Sub-criteria and TTS Clauses

Physical Behaviour is given 10% of the total score for the assessment of Train Works, alongside the 12 other sub-criteria, shown in appendix D (page 378). We do not know how this percentage was chosen. The relevant attributes of the desired train's *Physical Behaviour* are described across five different clauses in the TTS: TTS 3.7, TTS 3.8, TTS 3.9, TTS 3.10, and TTS 3.23. Each of these clauses has a weighting, as shown in Figure 6.16 above. For example, TTS Clause 3.7 describes aspects of *Gauging, Routes and Stepping Distance* related to the train and its infrastructure. A proposition that is articulated with this requirement can gain 25% of the total score for *Physical Behaviour*.

TTS clause 3.7 is part of a hierarchy that in turn contains 12 sub-clauses, 3.7.1.1 to 3.7.1.12 that describe various attributes related to *gauging, routes and stepping distance*, which is effectively about required clearances in tunnels, the connection between train and platform, and so on. For example, TTS 3.7.1.1 provides the following lengthy requirement that is reproduced below:

- TTS 3.7.1.1: The Unit (including all physical features such as underframe equipment, bogies, door light indicators, buttons, roof mounted antennae, stowed pantographs but excluding footsteps) shall have a swept envelope no larger than that generated by the Crossrail Class 345 Vehicle Model for all movement and behaviours (including operation in degraded conditions). For the lower sector the requirements of Appendix C C.2.3 shall apply. **Note this shall be demonstrated by the derivation of a KE [Kinematic Envelope] and comparison with the Crossrail Class 345 Vehicle Model and the swept envelopes contained in Appendix C (using ClearRoute™)** [Emphasis added]. The development of the KE shall take note of the guidance note GE/GN8573. Crossrail Class 345 Vehicle Model: Means the Crossrail and Network Rail authorised ClearRoute™ Crossrail Class 345 vehicle model which is designated within ClearRoute™ as LV- 345-1.

In this sub-clause (TTS 3.7.1.1) Crossrail define the measurement system to be used by Bidders when they articulate their propositions of trains. The software package, ClearRoute ™, is a tool for calculating clearances between railway vehicles and surrounding infrastructure. Bidders are instructed, in TTS 3.7.1.1, to create a model of their proposed train using this software. They are effectively creating a **model of a model**, using the software modelling package to model their proposition of a train, that is itself a model represented in documents and other forms. The Bidders are asked to compare the model of their proposition of a train to a *Crossrail Class 345 Vehicle Model* (LV-345-1), which has been created by Crossrail. We do not have a physical test track like at Rainhill, but the propositions of trains are required to prove themselves on a similar abstraction. The route through which the trains will navigate was brought into this action (loop 1, mobilisation of the world) using this software, with modelled infrastructure and a model competitor.

The other 12 sub-criteria within Train Works, and the associated clauses from the TTS, describe different aspects of the desired train, including further requirements regarding weight and seats. The mandatory requirements of stage one (above) included a maximum weight limit and minimum total capacity for seating and standing. It is at this second stage that specific requirements for seating are given.

A set of sub-criteria described as *Industrial Design* (Figure 6.17) is allocated 6% of the total score for Train Works.

Sub-criteria	**Relevant requirements, components and weightings** (Clause references relate to the Train Technical Specification and are deemed to include other requirements cross referenced in the relevant clauses)	
Industrial Design (6%)	Clause / Component	% of score
	3.19 Exterior Appearance and Livery	40%
	3.34 Passenger Environment	60%

Figure 6.17 Crossrail Train Works Sub-criteria and TTS Clauses - Industrial Design (including seating)

Within *Industrial Design* the TTS Clause 3.34, *Passenger Environment*, attracts 60% of the score. TTS Clause 3.34 includes some 98 sub-clauses, including the following examples:

- TTS 3.34.3.3: The FLU [Full Length Unit] interior shall provide seated accommodation for a **minimum of 450 passengers** [emphasis added] …
- TTS 3.34.3.6: The Unit interior layout shall allow for **a mixture of seated accommodation in the longitudinal and transverse configurations, with the distribution being approximately 2/3rd longitudinal seating** [emphasis added] …
- TTS 3.34.3.7: The Unit interior layout **shall not include 3+2 transverse seated configurations** [emphasis added].
- TTS 3.34.3.9: The **interior seated capacity and layout shall be calculated on the following basis** [emphasis added]: perch type seats shall be excluded from the seated capacity calculation; where tip-up seats are provided, they

> shall not be included in the seated capacity calculation if their deployed space is required to meet the standing capacity requirement; and where tip-up seats are provided in wheelchair space or open areas, they shall be included in the seated capacity.

A requirement for a minimum of 450 passenger seats is given (TTS 3.34.3.3). As described earlier, the realised Class 345 delivered by Bombardier has 454 seats in its full 9-car formation. A split of two thirds (TTS 3.34.3.6) for longitudinal (London Underground style) seating and transverse seating is also evident in the internal photographs shown earlier (Figure 6.11, page 215) of the realised Class 345 trains.

The 3+2 seating layout, which might increase seating numbers, is forbidden according to TTS 3.34.3.7. However, these requirements are not mandated, and so it could be possible for a Bidder to introduce 3+2 seating in their proposal of a train. This would mean that their proposition was inarticulate with this attribute, and it is the most articulate train that is selected as winner.

Alongside this technical evaluation of the Train and Depot Works there is also an evaluation of the *deliverability* of Bidders' proposals across the following criteria:

b) <u>Deliverability criteria</u>

- Train Works
- Depot Works
- Services
- Health and Safety
- Environment
- Responsible Procurement
- Assurance and Quality

The same approach is adopted. Each of these criteria is broken down into sub-criteria, with weightings allocated for scoring. These criteria will not be explored in depth here, but the purpose of this is to measure the ability of competitors to *translate* their propositions of trains into realised trains. This translation process is outside of the scope of this study, but it is interesting to note that the procurement taking place within the decision-laboratory does look forward to the required future translation.

One area to note is that Responsible Procurement (above) relates to the Greater London Assembly's responsible procurement policies and includes sub-criteria to assess the Bidder's proposals around Diversity, Strategic Labour Needs and Training, and Ethical Sourcing and the London Living Wage. The recommendations from the Government's Review of Public Sector Procurement described earlier (section 6.2.5) act upon this aspect of the articulation of propositions.

Proposals which pass stages 1 and 2 progress to stage 3 of the evaluation.

6.2.8.3 ITN stage 3 - commercial evaluation and negotiations

This stage produces a *Total Commercial Score* (TCS) for Bidders' proposals. This is defined as:

- TCS = weighted Net Present Value (NPV) Score + weighted Contractual Compliance Score

The first part of the TCS, the NPV score, is effectively the costs of building and supplying the trains, depot, and related services, over the expected 32-year duration of the trains and contract. Bidders were provided with an *Evaluation Model* to complete as part of their proposals. Crossrail reserved the right to adjust Evaluation Models, including for inconsistencies, errors, or *abnormally low tenders*. Crossrail then ranked Bidders' proposals relative to each other. The proposal with the lowest NPV (lowest cost) is awarded 100 points, with other proposals scored relative to this. Crossrail state that the weighted NPV score accounts for 65% of the Total Commercial Score (TCS).

The second part of the TCS is the Weighted Contractual Compliance Score and this accounts for the remaining 35% of the TCS. This is an evaluation of how compliant the proposals are with the requirements of the tender. This measures any qualifications, or gaps, between the Proposers' Bids and the requirements for the entire procurement. Evaluation criteria for this are provided to Bidders.

Finally, Bidders are ranked in descending order of their TCS, such that the Bidder with the highest TCS is ranked 1st, the second highest TCS is ranked 2nd, and so on. Crossrail can, at its discretion, then begin to undertake negotiations with one or more Bidders, according to this order of ranking.

The OJEU notice that launched this procurement stated that the tender would be awarded to the most economically advantageous tender (MEAT) in terms of the criteria stated in subsequent documentation. The most articulate proposition of a train is selected from within the decision-laboratory according to MEAT. Propositions of trains have been configured across three stages within the Crossrail decision-laboratory, that includes this ITN process. The most articulate proposition has passed stages 1 and 2, and then achieved the highest Total Commercial Score at stage 3. The winner can go forward towards contract award.

6.2.8.4 ITN stage 4 – contract award

With the withdrawal of Siemens in July 2013, the three remaining Bidders (Bombardier, CAF, and Hitachi) submitted revised bids in August 2013. In February 2014, the Government and TfL announced that the £1 billion contract to supply, deliver, and maintain 65 new trains and a depot had been awarded to Bombardier. The contract was signed on 19 February 2014. The Crossrail press release (Crossrail Ltd, 2014) stated that 65 new trains would be manufactured and assembled at Bombardier’s UK plant at Derby, supporting 760 UK manufacturing jobs and 80 apprenticeships, with around three quarters of the contract spend remaining in the UK economy. This press release illustrates the revised concept of how to produce new trains (loop 5, links and knots), with greater emphasis placed upon local production and impacts.

Bombardier’s winning proposal was the most articulate proposition of a train produced within the decision-laboratory. TfL would now work with Bombardier on the final designs for the trains, as the action moves to the translation of the proposition into a realised train, with the first planned for delivery in May 2017.

6.2.9 The realised trains enter service from June 2017

In September 2015 the first test train carriage rolled off the Bombardier assembly line in Derby (Haylen, 2019, p. 38) and was on the local test track in August 2016. A phased rollout was planned for the new trains to align with progress in the wider Crossrail programme. This phased introduction was to start in May 2017 and conclude by December 2019. The first phase introduced services between Liverpool Street in London and Shenfield in Essex, with 7-car units used because of shorter platforms. The first train entered service on 22 June 2017 and replaced Class 315 4-

car units. In July 2017, TfL awarded Bombardier a contract to supply a further five trains for use on the Elizabeth Line, taking its total order to 70 trains.

Subsequent planned stages were to introduce Crossrail services to other parts of the network: Paddington, Heathrow Airport, Abbey Wood, Maidenhead and Reading. However, delays in testing the trains and integrating the signalling systems, especially through the tunnels under central London, delayed plans significantly. The central tunnels connect the eastern and western sections straight through central London, from Reading and Heathrow in the west to Abbey Wood and Shenfield in the east. The full Crossrail service was planned to be in operation by December 2019, however, in early 2020 Crossrail Ltd stated that they expected the central section to open in summer 2021, with the full service planned to operate from mid-2022. Total costs for the entire Crossrail Programme were forecast to exceed £18bn, compared to the £14.8bn authorised in the 2010 Spending Review (Sean Farrell and Gwyn Topham, 2019).

In March 2019 TfL agreed a 20-year deal to sell and leaseback the 70 Class 345 trains (Clinnick, 2019) to a finance company, 345 Rail Leasing. This deal raised £1bn for reinvestment into London Underground. Financing was always part of the actor-network that produced the new trains, but it was provided by different actors through the process.

The final Class 345 was released from assembly at Derby by Bombardier at the end of Nov 2019 (RAIL, 2019, p. 28). The translation of propositions into realised trains was complete. However, delays with the Crossrail infrastructure project would lead to many of the Crossrail trains being placed in store at Old Oak Common, the depot built as part of this action. Despite this delay into full service, the new trains have been described as a “ray of light” (Dan Harvey, 2019, p. 18) in the larger troubled Crossrail project. The trains are in an actor-network with the infrastructure and delays there have meant that many trains are unable to act as trains. The expensive trains in store (Figure 6.18 below) have been associated with negative headlines (James Salmon, 2019) (loop 4, public representation).

Figure 6.18 Class 345 trains at Old Oak Common Depot

Source: (James Salmon, 2019)

Crossrail's new Class 345 trains have been described as the "first of a new class of train" (National Audit Office, 2019, p. 22). They have new systems and software that support high throughput operations. Operating as nine carriages they are nearly twice the length of a tube train. Each coach has three double doors to allow the rapid loading and unloading of passengers. Their wide gangways between the cars allow people to board and then move through the train. They are designed to carry 1,500 passengers, including seating and plenty of standing room. They can run at up to 90mph, with fast acceleration and braking capability. These are some of the attributes of the trains, combined with changes to infrastructure, that collectively act to achieve the rapid movement of large amounts of people – in line with the goal to increase capacity in London.

In terms of the focus of this research, the earlier analysis in Table 6.5 (page 219) found that the 9-car Class 345 trains are heavier per seat that the 4-car Class 315s that they replace, but their hybrid nature means they have a large total capacity of 1,500 that includes 454 seats. The new trains weigh an average of 35.4 tonnes per car compared to 34.4 tonnes for the Class 315, and 33.3 tonnes for the new Siemens Thameslink Class 700 trains. However, the Class 345 consists of 22.5m long vehicles compared with 20.2m vehicles for the Class 700 and 315. The Class 345s provides more floor space, which is valuable for high-capacity metro services.

The Class 345 trains, produced by Bombardier, do not just transport people, they also support 760 UK manufacturing jobs, 80 apprenticeships, with an estimated 74% of contract spend remaining in the UK economy. This wider economic contribution may be produced by construction of the new trains, their ongoing maintenance, and further work is generated because of the experience and capability resulting from the Crossrail programme. Recognition for this wider set of attributes emerged during the process, as described earlier, and involved HM Treasury, Unite the Union, Bombardier, and other actors in a very public discourse regarding the nature of procurement within the UK and EU. These actors are not directly involved in the strategic decision to produce new trains, but there can be no doubt that they demonstrated their ability to act. A different concept (loop 5, links and knots) emerged for how trains should be produced. The most articulate proposition was able to support capacity improvements and other goals, but it also had attributes associated with the wider benefits of local construction.

The fluidity of actor-networks that act and produce new trains was further illustrated by the financing part of this strategic decision. This changed as the strategic decision progressed: moving from a supplier requirement to a TfL responsibility, and finally back to a private financier. Financing was always part of the network, but it was provided by different actors in different relationships.

The success or otherwise of the Class 345 trains will become clearer as they continue to rack up service miles. The movement of large amounts of people in the central section during peak times will reveal the public’s perception of the strengths and weaknesses of the new trains. Those travelling on longer journeys may not be happy if they are unable to find a seat or need toilet facilities. Reliability and value for money will also become clearer over time (National Audit Office, 2014c, p. 10), as costs and benefits are realised and can be compared to forecasts and models.

What we cannot know is how the alternative propositions of trains, created by Hitachi and CAF, would have performed. Similarly, there were other propositions that were ruled out by the earlier withdrawal of Alstom and Siemens. All alternative propositions of trains remain unknown in practice – they were not translated, and they were unable to become realised trains.

Hitachi did not win the Crossrail procurement, but, in July 2012, they were awarded the £4.5Bn Intercity Express Programme contract for new trains for the Great Western and East Coast services. In 2011 Hitachi had selected Newton Aycliffe in County Durham as the site for their new UK factory. The production of this factory started in 2013 and it was opened in 2015. Hitachi Class 800 electro-diesel hybrid trains have been in service since October 2017, and Class 801 electric multiple units, have operated on the East Coast Main Line since September 2019.

CAF were the other competitor who lost out to Bombardier. In 2017 CAF announced that its UK factory was to be the Llanwern steelworks in Newport, Wales. It has since built several new trains, including the Class 195 DMU and Class 331 EMU. A total of 58 Class 195 2-car and 3-car DMUs were built for the Eversholt Rail Group, a rail industry ROSCO, to be operated by Northern Trains in the north of England.

Siemens, who withdrew from the Crossrail procurement in July 2013, went on to deliver the Thameslink Class 700 trains, as described earlier in this chapter.

Alstom withdrew from the Crossrail procurement in August 2011. In 2020, Alstom announced a Memorandum of Understanding with Bombardier Inc. to acquire Bombardier Transportation.

6.3 Summary

Both trains reviewed here are suburban Electric Multiple Units that can transport large numbers of people to address capacity and congestion problems in London. The Class 700 and Class 345 operate as longer formations (12-car and 9-car) than the trains they replace. Their material and physical form acts to transport more people. The trains, together with wider infrastructure programmes that are upgrading local infrastructure, act collectively to support an increase in capacity.

This research started with a focus upon weight (kg per seat) because of its importance to energy use and environmental emissions. The empirical analysis in Chapter 4 found that UK trains have generally been getting heavier over time, as measured by kg per seat. This is also the case for the Thameslink Class 700 and Crossrail Class 345 trains, which are heavier per seat than the Class 319 and Class

315 trains that they replace. The new trains have fewer seats that their predecessors. However, in terms of weight per car, the Class 700 trains are lighter. The Class 345 trains are marginally heavier than some of the trains they replace, although they have longer carriages with more floor space and a larger overall capacity.

Chapter 5 demonstrated that railways and trains are fluid concepts that can configure and re-configure a heterogenous collection of entities to act as a train. In these two strategic decisions the configuration of resources that act as trains can help to address capacity problems that have existed in this part of the network for decades. This capacity improvement has been achieved with trains that have been applauded by industry commentators for their lightweight designs, which are expected to deliver benefits throughout their operational life.

To investigate how the lightweight realised trains were produced the research focused upon the procurement process, where propositions of trains *are articulated*, and the most articulate was selected as the winner. These procurements were described (section 2.4) using the metaphor of a laboratory. In the same way that the "laboratory is an artificial setting in which experiments are organized" (Callon, 2001, p. 62), the procurement tender, including PQQ and ITT/ITN processes, creates an artificial environment, a *decision-laboratory*, in which propositions of trains are created, articulated, and evaluated.

Each decision-laboratory included a Train Technical Specification (TTS) that captures and conveys the characteristics of the desired trains. The TTS is part of the system by which propositions of trains will be measured and judged – it **helps to assesses whether propositions are articulate or not (adjective), but it also actively articulates propositions (verb).** Such tools and instruments act upon and articulate a proposition of a train "simply by measuring it," (Callon, 1998, pp. 23, 25) – disciplining behaviour and the configuration of resources that make up the train towards the things to be measured.

The winner from each action is the Most Economically Advantageous Tender (MEAT) – this is a system that is defined and measured within, and by, the decision-laboratory. The laboratory is not a sterile environment that is isolated and excluded from the wider social world, rather the *external* world can act and change the definition of MEAT and activities to produce new trains. The winning proposition, as defined by MEAT, is the most articulate proposition of a train. It is, by definition, the best articulation of a train produced within this laboratory environment – **it is connected to, and articulated with, the decision-laboratory that was created to produce propositions of trains.**

ANT's wider view of action was used as the main theoretical lens to understand how the propositions of trains were produced within the decision-laboratory. This approach abandons "the core / context model" (Latour, 1999, p. 100) that sees action happening in a core of activity, within a context that provides a background to the real action. In both recent procurements the *context* has proven to be active, with interventions from '*outside'* of the immediate procurement leading to disruptions to timescales, changes in the nature of the process, arguably contributing to some actors (Siemens, Alstom) exiting the process, and changing the concept of how trains should be produced. The Global Financial Crisis, HM Treasury, the London Mayor, threatened jobs in Derby and associated supply chains, newspaper headlines, and unions have all demonstrated their ability to act, and to shape the strategic decisions and production of propositions of trains. Relegating them to context and background does not reflect their contribution to this social process of production.

Latour's model (Figure 2.2, page 54 and Figure 5.1, page 114) has five circulating loops of activities and it was used to understand the articulation of propositions of trains within the decision-laboratory. Each of these loops is as important as the other to understand action. There is no inner core and surrounding context. The following sections summarise the research findings across each loop in the two strategic decisions investigated in this chapter.

6.3.1 Loop 1: mobilisation of the world (instruments)

This loop is about practices that mobilise the *real world*. Propositions are strengthened by connecting them with an external world that is mobilised and brought into the decision-laboratory. In these strategic decisions we do not have trains running on the real Thameslink and Crossrail networks, but we do have propositions of trains, in various forms, being shaped and evaluated on representations and models of the rail network. The current and future infrastructure on which the trains will operate is represented in technical documentation, computer models and other forms. Thameslink brings London underground tunnels into the action in the Train Infrastructure Interface Specification (TIIS), which represents the tight tunnels and the need for emergency evacuation through the ends of the train, rather than the sides. Crossrail uses a software package to model Bidders' propositions of trains against a model of the infrastructure and a model benchmark train created by Crossrail and others. The electric supply network for the trains is brought into the action, but the modelled network is *considered to be 100% receptive,* when calculating the return of power from the train's regenerative braking systems. This may not be the case for the real network.

The complex socio-material reality of a train is simplified, abstracted, and represented in a Train Technical Specification (TTS) developed for each procurement. This articulates various attributes of the desired trains against which propositions will be measured. For example, train acceleration and speed are measured by bringing in real places, and the timings of the current service. The Thameslink procurement used the Bedford to Farringdon route, together with timings for the current Class 319 services. The Crossrail procurement used the Shenfield to Tottenham Court Road route and stated that this must be achieved in 47 minutes, including stopping patterns and dwell times. Bidders did not have to run real trains on these real routes, but they did need to use the approved practices to demonstrate their propositions of trains achieving these targets. The test routes *represent* the rest of the network and propositions are strengthened when they demonstrate their performance on these 'test tracks' that have been mobilised and brought into the decision-laboratory.

6.3.2 Loop 2: autonomisation (colleagues)

The second loop considers the actions of industry insiders in this collective action. This includes the colleagues, professions, disciplines, "organisations, resources, statutes, and regulations" (Latour, 1999, p. 103) that are closely associated with the production of new trains. There are a diverse group of institutions and colleagues within this loop, and they strengthen the network and articulation of propositions with their expertise. The early stage of network formation is developed within the railway and related professions.

The DfT sponsored the Thameslink procurement for several reasons, including a desire to reduce long term costs to the whole rail system. Crossrail Ltd, a wholly owned subsidiary of Transport for London, jointly sponsored the Crossrail procurement, because integration with the wider programme was critical. The institutions are Prime Movers in the earlier analysis. They issue a call for expressions of interest and respondents must demonstrate their relevant experience if they are to be considered for inclusion within the network. Respondents are provided with a list of stakeholders, although they are not allowed to make contact without the permission of DfT or Crossrail. The lists identify industry stakeholders who are responsible for different parts of the railway, such as Network Rail, the Rail Safety and Standards Board (RSSB), rail regulator, and others. The Bidders themselves are global train manufacturers and are part of this group colleagues and professionals. They have specialist knowledge and skills related to the production of new trains, but that does not imply uniformity regarding the best ways to produce trains.

The most notable feature of this loop for the two strategic decisions is arguably related to an absent member. As described in Chapter 5, at the time of privatisation British Rail's rolling stock was sold to three ROSCOs (rolling stock companies). Their industry role was to own and maintain the rolling stock, and lease it to train operating companies, who would operate the train service. Although both strategic decisions involve the procurement of new rolling stock, there are no ROSCOs directly involved. Instead a mini-ROSCO (Butcher, 2017, p. 6) was effectively created by the Thameslink tender, with the Siemens-led consortium arranging financial capital to build the trains, which was recovered by lease payments from the Train Operating Company. No ROSCO was originally involved in the Crossrail procurement, but the ownership of the trains changed. The initial intention was, like Thameslink, for the winning supplier to finance and own the trains. However, this changed to public ownership by TfL, until March 2019 when TfL sold the trains to a leasing organisation, which can effectively be considered as a new mini-ROSCO.

The ROSCOs omission from these procurements, and the changing sources of finance, further demonstrates a fluidity in the actors that produce new trains.

6.3.3 Loop 3: alliances (allies)

This loop strengthens the networks producing the new trains by reaching out and connecting the articulation of propositions with a wider set of alliances. The translation of the most articulate proposition into a realised train requires financial capital. This brings in allies beyond rail that can provide equity, debt, and other forms of finance, insurance, and risk management. The Crossrail action created an alliance with local businesses, who would benefit from the improved services and contributed to the Crossrail programme via a supplement to London business rates. Allies support the action and make the network more robust in response to any destabilising forces that may seek to detract from the network, or to support competing outcomes.

The railway also creates alliances because it can be a significant construction enterprise, as well as a provider of transportation services. The Crossrail procurement references Heathrow Airport Limited, Canary Wharf Group, Berkeley Homes and others who are allies connected to this action. These relationships may be formed because of the construction and development activity of Crossrail, or because of the future services when they become operational. For example, faster connections to Heathrow will form an alliance between the trains, railway, and Heathrow. This alliance strengthens the network producing new trains for Crossrail.

The geographic spread of railway services means that they often travel through several political constituencies, with the resulting entanglement of political leaders and organisations within those geographies. The award of Thameslink to Siemens drew in political representatives for Derby, home to Bombardier’s factory. Threats to the local labour and supply chains created alliances, that did not reverse the Thameslink decision, but they did change how these strategic decisions were made in the future. The Treasury was effectively brought into the network, when they issued supplementary guidance to the Green Book, clarifying how wider costs and benefits should be recognised. The Bombardier proposition of a train, developed within the Crossrail procurement, was strengthened by alliances in the Derby area and with local supply chains.

6.3.4 Loop 4: public representation

The fourth loop represents a movement of this action into the wider public domain, with the public mobilised and represented in various ways in the actions to produce new trains.

The public who travels on railways are drawn into these actions through their experience as passengers. If the railways are congested, then there is likely to be positive support from passengers for actions to increase capacity. However, passengers will only see this benefit when the realised trains, and associated infrastructure improvements, are complete. In the case of Thameslink, a full service is in operation and the public can experience the trains. However, a full service is not yet operating for Crossrail, because of delays to the wider infrastructure programme. The Crossrail trains have all been delivered and are ready for service, but newspaper pictures show idle trains sitting at the newly built depot. Until the trains and signalling systems in the new central sections are safely tested together, then the trains cannot provide the service and deliver on *the promise* to the passenger.

Passenger Focus and London TravelWatch are institutions that *represented* passenger interests during these strategic decisions. Their research found that 3 + 2 seating was universally unpopular among passengers. This research acted and this form of seating was forbidden in both procurements, which contributed to a reduced number of seats on the new trains, compared to their predecessors. How passengers perceive the availability of fewer seats, especially on longer journeys, will be discovered over time. Passenger standing room was represented in both procurements, which required the propositions of trains to carry people standing at a density of 4 passengers per square metre. Again, the effectiveness of this representation will be revealed over time, with COVID-19 highlighting fundamental problems with such assumptions in 2020.

Passengers and their comfort are mobilised in both procurements, but this is not real people sitting on real chairs, rather it is comfort indices and standards for ride comfort (British Standards, 1999), which are interacting with fire and safety standards regarding the materials used in seats. The propositions of trains produced within both procurements were required to have seats that achieved levels of comfort measured by a *comfort index*. The comfort index *represented* passengers and their comfort. However, complaints about the new Thameslink trains talked about “bone hard fabric seats with poor legroom" (RAIL Opinion, 2017, p. 57) and headlines in national newspapers have described “ironing board seats” (Graeme Paton, 2018). The models of comfort are being revised (RSSB, 2019) and updated.

There are various other ways in which the public is brought into both procurements. People with disabilities are represented though legislation for Persons with Reduced Mobility (PRM) that is a mandatory requirement for passenger trains from 1 January

2020. Neighbours to the railway are recognised in the Crossrail procurement, which highlights potential negative impacts from noises associated with the railway and encourages propositions that address these concerns. The movement of people through gangways between carriages is important to allow congestion to be eased. The required width of this gangway is defined by Crossrail as the width of two 95th percentile adult UK male passengers. These adult UK males are brought into this action in the form of statistics (also loop 1, mobilisation of the world).

Understanding how the wider public is mobilised is relevant to all strategic decisions and actions. The strategic decisions of interest here are to produce new passenger trains. This might suggest that it is even more important to ensure that propositions of trains are strengthened and made more articulate with a wider public, as represented by this loop.

6.3.5 Loop 5: links and knots

The fifth loop, *links and knots*, can be considered as the conceptual knot that holds the heterogenous collection of resources together. This could be the collection of resources that acts as a train, or the collections of resources that comes together to produce a proposition of a train. Chapter 5 showed how the concept of the railways and trains has changed over time and this can reconfigure the heterogenous collection of resources required to produce new trains and deliver a railway service.

It was proposed at the end of Chapter 5 that the concept of the railways at the time of these procurements could be described as *industry-led integration within the functionally specialised and contractual railway*. This admittedly inelegant description seeks to capture the privatisation concept, with railway functions split among specialists, but also increased motivation within the industry to join-up, sometimes despite the incentives that can exist. The action to produce new trains reflects this concept. In each action DfT and Crossrail took on the role of sponsors because of the need for a long-term and industry-wide perspective. This was required to deliver trains that achieved wider industry goals, rather than the narrow goals of any specialist within the railways. The Rolling Stock Companies (ROSCO) were created at privatisation, however they were notably absent from these actions. These actions are effectively producing a *mini-ROSCO* (Butcher, 2017, p. 6).

The concept of how to produce new trains – the links and knots – can be seen to have shifted during the period of these two procurements. The concept at the centre of the early Thameslink strategic decision included financing for the trains and depots that was to be provided by the Bidders. Trains were to be produced this way, until it became unviable when the Global Financial Crisis and Eurozone problems made it difficult for private companies to access credit markets. The financing part of this production moved into the public sector, before returning to private sector provision as credit markets re-opened. The links and knots locked in financing as part of this action, but there was a fluidity demonstrated in how resources were configured to achieve this.

The Thameslink strategic decision led to headlines of job losses and the closure of Bombardier's Derby factory. The production of new trains became publicly connected to employees, apprenticeships, unions, politicians, communities, newspapers, national self-interest, and the Treasury, who recognised the "wider costs and benefits of infrastructure spending and investment" (HM Treasury, 2011b, p. 9). The Treasury's supplementary guidance was brought into the Crossrail strategic decision. Recognition of the extended network associated with the production of new trains led to **a modified concept of how trains should be produced**. The specialist focus of privatisation has been **modified to recognise the importance of *where* the train was built, and how this strategic decision was connected to the local and national economy**.

Both strategic decisions made their selection on the broad basis of the 'most economically advantageous tender' (MEAT) (House of Commons Transport Committee, 2011, p. 12). Each procurement then went on to describe to participants how it defined MEAT. The production of these new trains forbade the use of 3 + 2 seating, because passenger feedback said it did not produce a good passenger experience. The new trains produced have been recognised for their lightweight designs that will help with acceleration and deceleration for high throughput, but will also save energy, maintenance costs, and environmental emissions. **The concept of MEAT is defined by, and within, the decision laboratory, and it can mean whatever we want it to mean.** Looking beyond these two strategic decisions, the National Audit Office has pointed out that "transforming the transport system, supporting economic growth and other national aspirations" (National Audit Office, 2014b, p. 7) were objectives for High Speed 1 (the Channel Tunnel Rail Link) and High Speed 2 (the planned high speed link from London to the North). These objectives go beyond meeting immediate transport needs and recognises a wider role for rail and transport.

The actor-network that performs as a train is a material-semiotic configuration of physical objects that are caught up and shaped in relations that carry meanings (Law and Allaskuvla, 2019). The concept of the railway has changed over time, it has changed during the two strategic decisions discussed in this chapter, and it will continue to change in the future. **Different meanings will produce different trains. If we want trains to be lightweight, then these actions provide good evidence that we can make them lightweight. Weight is one of many attributes associated with different collections of resources that can all act as trains. Giving preference and priority to weight is likely to produce lightweight designs, but this will impact other desirable and non-desirable attributes. Our decision-laboratories are great *places* to experiment and create the trains that we want.**

7 Reflections and Conclusions

The introduction to this thesis described strategic decisions taking place at Rainhill in 1829, and more than 180 years later with Thameslink and Crossrail. Three strategic decisions at two different points in time, but all, ostensibly, seeking *the 'best' trains* for their railways. This juxtaposition was used to show the changes, and many similarities, common to such strategic decisions. This chapter returns to these three cases and uses them to illustrate some of the main lessons learnt during the development of this thesis. This starts with a reflection on how Actor-Network Theory has helped to think about and understand strategic decision-making.

7.1 How to understand strategic decision-making

Models of decision-making often describe a progressive shift from instability to stability, or convergence around the final selection, as "multiple possibilities are progressively narrowed down until a single outcome is achieved" (Dugdale, 1999, p. 131). Each of the three cases do fit this description. Decisions are made to award the Rainhill prize to Robert Stephenson, and the contracts for Thameslink and Crossrail are awarded to Siemens and Bombardier, respectively. However, using the theoretical model developed in Chapter 2, the concept of *converging* upon a single outcome can be defined more precisely as converging upon a particular *proposition* of a train. Stephenson's *Rocket* was the winner because **it was the best proposition of a train at Rainhill**. Siemens and Crossrail are the winners because they were **the best propositions of trains in the Thameslink and Crossrail procurements**. The selection of a proposition can be considered as an outcome, but it is an outcome which needs to be translated to become a realised train before its use and value is tested in the real world. It is the realised train that carries passengers, moves goods, consumes energy, produces emissions, and has other attributes of interest.

The metaphor of a *decision-laboratory* was introduced in Chapter 2 to characterise the strategic decisions taking place at Rainhill and for Thameslink and Crossrail. This metaphor aimed to capture the exploratory and experimental nature of what is taking place – a characteristic that can easily get lost in the idea of decision-making as a rational selection process. Calling the *ordeal* at Rainhill a *decision,* or even a *strategic decision*, does not really capture the hissing, spitting experiments taking place in front of cheering crowds. The Thameslink and Crossrail procurements did not involve experiments taking place at a single physical location, like Rainhill, but these actions exploded into front page headlines when there were potential threats to jobs and local economies *connected with* the decisions. The five-loop model, described in Chapter 2, was used to understand the action within this *place* – the decision-laboratory – where propositions are articulated. What follows is a summary of this model applied to Rainhill and the two recent strategic decisions.

At Rainhill we have a model track (loop 1, mobilisation of the world) to simulate the Liverpool & Manchester Railway (L&MR), which is not yet complete. Competitors' locomotives are no taller than fifteen feet from the ground to the top of the chimney, because they were given this height limit that *represented* tunnels and other parts of the real railway infrastructure. A weighing machine at the site measured the contenders and their load to carry, which was allocated using an agreed approach. Weight and the weighing machine effectively represented damage to the track, fuel costs, and the ability of motive power to haul people and goods. Locomotives hauled rocks and stones to represent passengers and goods that they would carry in the future. Timing points were used to assess speed, with positions on the test track marked and monitored by timekeepers. Competing locomotives were required to run back and forth 10 times on the test track, with this distance equivalent to the real Liverpool to Manchester railway. At the end of each run, Judges, appointed by L&MR, recorded the time, and the quantity of fuel and water used, which provided an estimate for future operational performance.

In 1829 there were only 50 locomotives in the world. The railway profession (loop 2, autonomization) was developing and mostly based around coal mines and stationary steam engines. The emergence of a new profession is evident in the judges appointed by L&MR Directors for the Rainhill trials – a chief engineer of a colliery, a steam engine factory owner, and an inventor of cotton spinning machinery. *The Rocket* locomotive was built by Robert Stephenson, the son of George Stephenson, who built the Stockton & Darlington Railway in 1825, discussed in Chapter 5. The early locomotive pioneers at Rainhill each brought their own ideas about how to make locomotives and there were very visibly different designs. The engineers, and the developing profession of locomotive design, were constantly finding new ways to make locomotives act and overcome challenges, such as the ability to *consume their own smoke* and ensure safe operation of high-pressure boilers near people.

The promise of cheaper and better-quality transport created many alliances (loop 3, alliances) with local traders, merchants, bankers, politicians, and others. The Directors of the L&MR, who offered the prize at Rainhill, were also local merchants and traders from Liverpool and Manchester. These allies provide support to help progress this action and make the network more resilient to overcome forces of resistance. Those opposed to this action, including the existing road and canal networks, would try to stop it, but if there were objections at the time, they failed to stop the action progressing.

The public (loop 4, public representation) were given a grandstand to watch the Rainhill Trials. Mixed with the excitement for the new locomotive engines there was also a fear, no doubt increased by the noise, smell, and early reliability problems and risks associated with high pressurised steam engines. To comply with the Act that permitted development of the railway every Engine in the competition was constructed to use coke, which produces low emissions of smoke – the coke acted to reduce smoke. Acceptance of these new creatures was evident when, on the final day, the public were happily taking free rides and travelling at speed on Stephenson's *Rocket*.

The different loops of the *ordeal* at Rainhill are held together (loop 5, links and knots) by the need to identify if locomotives were an acceptable method of power to move people and goods – to act as a railway. At this time, railways could be formed using horses, gravity or even people as power sources. Engines increasingly became part of the railway, but this was initially in the form of stationary engines hauling carriages via ropes and pulleys. Stationary engines were more robust than early locomotives and did not pose weight problems for early fragile track. An earlier report that led to Rainhill had found marginally in favour of stationary engines. Locomotives are under trial at Rainhill, to determine if they can act as a train safely, efficiently, and effectively. Chapter 5 characterised the concept of the railways following Rainhill as a *multiplicity of local railways*, reflecting the individual and bespoke nature of these networks that were configured for their specific circumstances and geographies. The collection of resources that could act as a train and provide a railway service was visibly diverse at this time.

Like Rainhill, the Thameslink and Crossrail procurements do not have trains running on the real Thameslink and Crossrail networks. However, modelled parts of the route are brought into the laboratory (loop 1, mobilisation of the world) as timing points to measure acceleration and speed. Thameslink uses the Bedford to Farringdon route. Crossrail uses the Shenfield to Tottenham Court Road route. Instead of the stipulations and conditions produced at Rainhill, we have Train Technical Specifications (TTS) and other documentation, that described how competing propositions of trains will be measured and assessed. Bidders need to use approved practices – instrumentation and measurement tools – to demonstrate that their propositions can achieve targets and performance requirements. Propositions of trains are tested using the current, and future, infrastructure that is represented in the laboratory. Propositions of trains for Thameslink must work with London underground tunnels, that have limited side access. Crossrail uses a software package to model Bidders' propositions of trains against the modelled infrastructure. The future infrastructure, on which the *propositions are operating*, has longer platforms and can accept regenerated power from the trains' regenerative braking systems, whereas this capability does not exist on the real railway at the time of these strategic decisions.

When Crossrail and Thameslink issue a call for expressions of interest, they receive responses from global rolling stock manufacturers (loop 2, autonomization), experienced in producing many different types of trains. These institutions have specialist knowledge and skills related to the production of new trains, but that does not imply uniformity regarding the best ways to produce trains. The Bidders are provided with a list of industry stakeholders, who are responsible for different parts of the railway, such as Network Rail, the Rail Safety and Standards Board (RSSB), rail regulator, and others. The development of propositions within the laboratory must connect (articulate) with these industry institutions and activities. The most notable feature of the Thameslink and Crossrail procurements is arguably the absence of ROSCOs (rolling stock companies) demonstrating a fluidity in the configuration of resources to produce propositions of new trains. Thameslink effectively create a mini-ROSCO (Butcher, 2017, p. 6), whereas Crossrail adopt public financing and ownership, before also moving to a mini-ROSCO in March 2019, when TfL sold the trains to a leasing organisation.

The benefits of improved services resulting from Crossrail created an alliance (loop 3, alliances) with local businesses, who contributed to the Crossrail programme via a supplement to London business rates. Further alliances were formed with Heathrow, through the connection between the airport and central London. Housing developers were brought into the network, with new developments along the route. Both strategic decisions build relationships because of associated construction and development work, as well as the benefits of future services. Political representatives for Derby, home to Bombardier’s factory and local suppliers, were drawn into the action with the award of Thameslink to Siemens. This did not reverse the Thameslink decision, but the Treasury was subsequently brought into the action when they issued supplementary guidance for future decisions, including Crossrail.

Crossrail and Thameslink may not have had a grandstand, but the public (loop 4, public representation) who travel on these railways are involved in these actions as passengers. Experience of congestion on old trains is likely to generate support from passengers, but delayed delivery into service may lead to frustration. Passenger Focus and London TravelWatch are institutions that *represented* passenger interests, with their research shaping the trains, especially the seating configurations. Passengers and their comfort are mobilised in both procurements using comfort indices, which perhaps did not prove too representative given subsequent complaints regarding seat comfort and leg room of the realised trains. People with disabilities are represented in the action though legislation and research. Neighbours are in the laboratory, represented in documentation that encourages reduced noise levels associated with railway operations and depot activity. The required width of the gangway between Crossrail cars should allow two 95th percentile adult UK male passengers to pass.

Chapter 6 discussed in detail what is at the centre of, and holding together (loop 5, links and knots), the different loops of the Thameslink and Crossrail actions. Capacity was key to the early *problematisation* of the trains, and both actions are achieving this through new trains connected to (articulated with) infrastructure improvements. The concept of the railway at this time was characterised as *industry-led integration within the functionally specialised and contractual railway*. Both DfT and Crossrail took on roles in response to known industry problems, as they sought to bring a long-term and industry-wide perspective to these strategic decisions. The concept of the railway appeared to develop during each procurement, with a greater value placed upon *where* the train was built, and how this strategic decision was connected to the local and national economy.

So, we have activities taking place across five circulating loops, within decision-laboratories that are actively involved in the production of propositions of trains. In each case a convergence does take place, and a winner is identified. We could say that the Judges selected *Rocket* as the winner, according to pre-agreed stipulations and conditions. However, those stipulations and conditions were modified during the process to reflect new knowledge formed during the Trials. The Judges were not removed observers neutrally applying rules, rather they were actively engaged in this action, gathering timing data, recording fuel consumed, and providing opinions when the conditions and stipulations needed to be adapted, as was the case with *Novelty* and *Sans Pareil*. DfT and Crossrail also produced pre-agreed criteria, against which they judged Bidders. However, as discussed in Chapter 6, *external* events delayed and modified the process to identify winning propositions. Like at Rainhill, rules and timetables were clarified and modified. In both Thameslink and Crossrail, the winning bid will be the Most Economically Advantageous Tender, but MEAT is not like gravity, a property or force *out there*. On the contrary, MEAT is defined within the laboratory and can be re-defined according to the needs of the laboratory. Strategic decision-making often implies that there is an “actor who actively chooses” (Mol, 1999, p. 74), but that does not fit the picture described here. Instead, of an actor choosing I propose that **the winner is the best proposition of a train produced by the laboratory**. Decision-laboratories are valuable *places* that support and enable decision-making. They are not passive and removed from the action taking place to shape and develop propositions of trains. **The decision-laboratory is an active site of development in the production of propositions.** Whether this is a good decision will become clear over time as the realised trains enter service.

The strategic decision taking place in 1829 used Rainhill as a *decision-laboratory* for experiments to find the best locomotive for the L&MR. The winner was the one that is most articulate to, or connected with, the laboratory and the experiments taking place there. *Rocket* was the only locomotive to complete 10 laps twice, for a total of 70 miles. *Novelty* achieved a higher average speed (15mph vs *Rocket’s* 14.2mph) but failed to complete the return leg. *Sans Pareil* completed 27 ½ miles but used 2.3 lbs.

of coke per ton per mile, compared to 0.91 lbs per ton per mile for *Rocket*. At this laboratory excited onlookers became passengers, as Stephenson gave them rides – a mass in motion involving people, instead of the stones used during the experiments. Stephenson's *Rocket,* and his other locomotives, went on to become realised trains operating as part of a successful railway between Liverpool and Manchester.

Thameslink and Crossrail also involve a decision-laboratory and experiments to find the best trains for their railways. They do not have a physical test track, like at Rainhill, but use computer models and simulations. Attributes of the *propositions* are measured and assessed against the modelled railway. For example, the modelled electric supply network can accept power from the onboard regenerative braking of propositions of trains, even though the real network may not be able to do this, at least for now. Passengers are not in a grandstand, but they are represented by industry institutions, legislation, in research reports, in models of comfort, and statistics regarding body size and width. The realised trains for Thameslink and Crossrail have been applauded by industry experts for their lightweight designs, that are expected to deliver benefits through their expected 35-year life. However, unlike *Rocket* they are not competing with stagecoaches running on rutted ground, and Thameslink passengers have expressed dissatisfaction with *ironing board* seats. Despite this specific problem, judging the success of these new trains will take more time to develop a fuller picture of their performance in operational service.

To conclude, strategic decision-making can be understood as a collective action, that occurs within a metaphorical decision-laboratory, that produces *propositions*. These decision-laboratories are valuable *places,* in which *propositions* are actively developed through a collective effort that reaches out across five circulating loops. The winning proposition is the most articulate within the laboratory – it is articulated with (connected to) the laboratory – but it remains, effectively, *a good guess*. The effectiveness of the laboratory, and this guess, will be discovered later, when the *proposition* is *translated* into its *realised* form.

A chart (Figure 1.5) showing trains getting heavier over time provided the frustrating starting point for this research. The next section uses this understanding of strategic decision-making to help explain why passenger trains have got heavier over time.

7.2 Explaining heavy trains

The empirical analysis in Chapter 4 found supporting evidence for an increase in weight per passenger seat. Across a large dataset of different types of passenger trains the average weight per seat for those introduced during the 1970s (Table 4.9, page 109), was 493 kg/seat, which increased to 524 (1980s), 577 (1990s), and then 748 for trains introduced during the 2000s. This dropped back to 707 kg/seat for the most recent trains, introduced since 2010, but this is still an increase over earlier decades. The analysis found that this was attributable to both increasing vehicle weight and a reduction in the number of passenger seats. An average car in a trainset introduced during the 1970s weighed 34.3 tonnes, and carried 70 passengers, whereas those introduced during the 2000s weighed an average of 44.6 tonnes and carried 60 passengers.

Weight increase is not an inevitability. The analysis of suburban Electric Multiple Units (EMUs) found a reduction in vehicle weight for the most recent trains, which includes the Thameslink and Crossrail trains, although they provided fewer seats than their predecessors. A suburban EMU train, introduced after 2010, weighed an average of 33.9 tonnes per car – lighter than trains introduced during previous decades in the analysis. However, suburban EMU trains introduced after 2010 only had 54 passenger seats per car on average, compared to earlier trains with 69 to 81 seats per car.

A train was described in Chapter 2 as a material-semiotic entity – it consists of *physical and material things* caught up, and shaped, in relations (Law and Allaskuvla, 2019). A collection of resources – human and non-human – act, collectively, as a train. Different actor-networks can act as trains in different ways, and they will have different attributes, such as weight, and the number of passenger seats. To understand why one train is heavier than another, we could simply list the *material things* that make up the train, and add up their individual weights, to arrive at the total weight of the train. Although this could provide some useful insights, it does not explain **why** those different *material things* have been brought into this network and configured in this way. To understand why a particular configuration of material objects exists, we need to understand the meaning attached to relationships between those objects. The analysis in Chapter 6 allows us to do this for the Thameslink and Crossrail actions.

To understand how heavy trains were produced, we can look to the recent Thameslink and Crossrail procurements that have bucked the historical trend of increasing train weight. Thameslink and Crossrail have produced notably lightweight realised trains, albeit with fewer seats. These realised trains, running on the Thameslink and Crossrail networks, were *translated* from earlier propositions of trains. To understand the lightweight realised trains, we need to understand the *propositions*. Without access to the commercially sensitive bid documents, it is not possible to know for sure that these earlier *propositions* also had attributes of lightweight and fewer seats, however the analysis in Chapter 6 investigated how *propositions* were articulated within each decision-laboratory.

In terms of weight, we know that the Thameslink procurement **did not mandate a weight limit** for the propositions of trains, but the Train Technical Specification (TTS) articulated that *a full-length unit should weigh less than 401 tonnes* (TTS 5.3.1). The actual weight of the 12-car Class 700 train (the realised train) is 399.6 tonnes. We know that Crossrail **did mandate a specific weight target**, with a full-length unit required not to exceed 350 tonnes (TTS 3.5.1.1). The actual weight of the 9-car Class 345 train (the realised train) delivered into service is 318.4 tonnes.

Like the weighing machine for competitors at Rainhill, both procurements measured and scored weight as part of the action to identify the most articulate proposition. For Thameslink, we can say that weight (TTS 5.3, Unit mass) attracted a score[7] of 0.8064% of the total, which is small, but significantly larger than, for example, the score[8] of 0.1638% given to comfort. Crossrail *propositions* were given a mandatory target (described above), but weight was further assessed and scored beyond this. The weight targets accounted for a maximum of 3.2% [9] compared, for example, to 1% [10] for comfort. Both scoring systems suggest that weight was relatively important in the articulation of propositions of trains taking place within these decision-laboratories, at least when compared to comfort, as an example.

In terms of the seating available on these propositions of trains, we know that Thameslink had articulated (TTS 5.2.1) a minimum level of seating (572 standard,

[7] 12% (Unit mass) x 16% (Unit requirements) x 60% (TTS) x 70% (Technical Requirements)
[8] 3% (Ride Quality) x 13% (Train wide functions) x 60% (TTS) x 70% (Technical Requirements)
[9] 40% (Unit weight targets) x 8% (Energy and weight)
[10] 10% (Ride and Stability) x 10% (Physical behaviour)

48 first class) required for full-length units. This total of 620 seats compares with the Class 700/1 12-car Thameslink realised train, which has 672 seats in total. The Crossrail procurement required propositions to have at least 450 seats and total capacity (seated and standing) (TTS 3.34.3.2) to be a minimum of 1,500 passengers. The Crossrail Class 345 realised train, subsequently delivered by Bombardier, has 454 seats and 1,500 total capacity.

Both procurements also articulated aspects of how the seats should be configured, with 3 + 2 seating explicitly forbidden in both the Thameslink and Crossrail actions. This type of seating, which had been used on some of the trains being replaced, was disliked by passengers, according to research brought into the action (Passenger Focus and London Travel Watch, 2008, p. ii). Crossrail also required a distribution of approximately 2/3rd longitudinal to transverse seating, reflecting the hybrid nature of this metro and mainline service.

Therefore, the lightweight Class 700 and Class 345 realised trains can be explained by a decision-laboratory that articulated weight as an important attribute. Fewer seats can be explained by passengers' dislike of 3 + 2 seating, with their feelings represented in the action taking place within the decision-laboratory by institutions and research. We do not know how the weightings given to different desired attributes were derived, but we do know that DfT and Crossrail took a leadership role for the procurement, because of a recognised need for a long-term and industry-wide perspective for new trains with expected 35-year lives. We do not know whether other bidders produced *propositions* with less weight and more seats than Siemens and Bombardier. This was the case at Rainhill, where *Novelty* was the lightest competitor, however weight was only part of the articulation of a winning proposition. The winning Bidders for Thameslink and Crossrail produced *propositions* that were articulate with their respective decision-laboratories. In the case of the Crossrail procurement, articulation also included revised guidelines for responsible procurement issued by the Treasury, which emphasised the wider social and environmental impacts associated with such strategic decisions.

If we look beyond the attributes of weight and the number of seats, then we can clearly see the need for increased capacity in the bodies of both trains. Capacity was a critical objective, and central to the early problematisation identified by DfT and Crossrail. The Crossrail Class 345 has three pairs of wide double doors per car, the

Thameslink Class 700 has two pairs per car, and both trains have these doors centrally located to support a high throughput of passengers with quick loading and unloading. Not all trains are like this. For example, Class 158 Diesel Multiple Units (DMUs) were introduced in 1989 and have been used across various parts of the UK network, including longer distance services, such as Liverpool to Norwich. Unlike the Class 345 and Class 700 trains they have a pair of narrow double doors at each end of a car. The narrow width of the Class 158 doors means that passengers must queue to leave the trains, which does not support rapid loading and unloading, however this configuration still *acts* as a train. The Class 158 may have attributes that produce longer dwell-time at stations, but it may have positive attributes, such as reduced heat loss in the carriages compared to trains with large double width doors. There are many ways to arrange resources to act as trains.

Given what we know about the production of propositions for Thameslink and Crossrail, which were translated to become the lightweight Class 700 and Class 345 trains, then it is possible to infer that heavy trains (kg per seat) were translated from earlier propositions, produced in, and by, decision-laboratories that were inarticulate with respect to train weight relative to seating. Producing lightweight trains, or trains with other desirable attributes, requires decision-laboratories that are articulate to weight. Decision-laboratories are active places in which propositions are articulated. Propositions of trains can be configured, and re-configured, much more easily than realised trains. Experiments taking place in a decision-laboratory allow us to test different propositions before we select the most articulate to go forward for translation into a realised train.

However, the articulation of propositions of trains in a decision-laboratory cannot avoid certain challenges that affect all strategic decisions. These challenges can lead to problems and dissatisfaction that are discovered later as propositions are translated into their realised form. Each of these challenges are explored next.

7.3 Three challenges for strategic decision-making: treachery, adaptability, and change

The strategic decision to produce new trains involves the articulation of propositions of trains, with one (usually) proposition chosen as the winner, which is then translated into a realised train. The metaphorical decision-laboratory in which propositions are produced, articulated, and a winner is selected, was described in Chapter 2 as *a manufactured environment that exists for a specific purpose – to produce a best guess, or estimate, of a train to operate in the future on the railway of interest*. An ideal situation would be for a decision-laboratory (procurement etc) to produce a strong field of propositions, with the most articulate proposition (the best guess) selected and then translated into a realised train, which was subsequently discovered to be a great train. This is not a naïve model that ignores, for example, bribery and corruption influencing the selection of the winner. Quite the opposite, producing a best guess requires a decision-laboratory that actively seeks to eliminate these types of distortions, using whistle-blower processes, and so on. Ways to improve strategic decision-making will be discussed later. However, if we assume that the decision-laboratory is set up to produce a best guess of the best train to operate on the railway, then there are three challenges that can stop this happening. These challenges impact the effectiveness of all strategic decision-making.

7.3.1 The treachery of model trains

The first challenge to the effectiveness of strategic decision-making relates to treachery. This treachery arises because, as discussed in Chapter 2, *the gap between the world of language and the real world "shows no sign of being filled" (Latour, 1999, p. 148), because our symbols, thoughts and representations are not the thing (referent) to which we refer*.

Propositions of trains, and realised trains, are distinct entities that exist in two separate worlds that could be described as a *laboratory world*, and an *operational world*. The laboratory world aspires to *represent* the operational world, but there is a gap that cannot be bridged. The title of this thesis, *The Treachery of Strategic Decision*, borrows from René Magritte's *The Treachery of Images*. This *treachery* is illustrated with the diagram below, showing Magritte's painting next to a model train of *Rocket* and a representation of the Thameslink and Crossrail propositions contained in "around 7,000 pages" (House of Commons Transport Committee, 2011, p. 63) of documents.

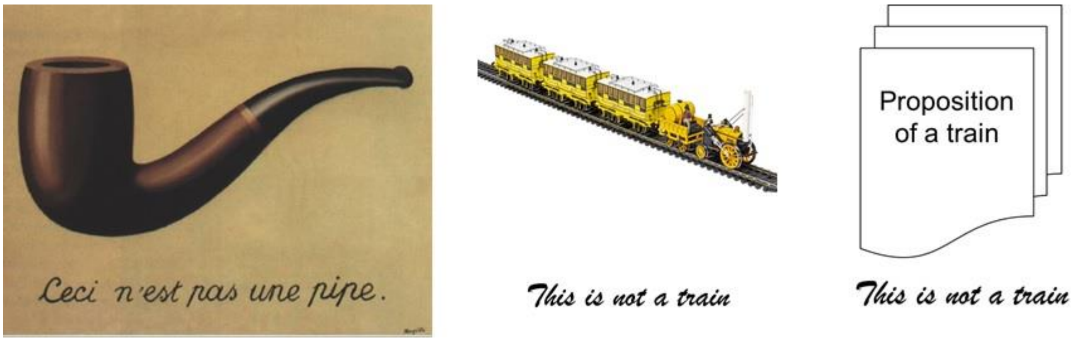


Figure 7.1 Borrowing from René Magritte. This is not a train

Source for model Rocket: Stephenson's Rocket Train Pack, Centenary Year Limited Edition – 1963, Hornby Trains

The proposition of a train and the realised train are not the same type of things, but there is a relationship between them. However, *translation problems,* in moving from one to the other, can mean that a best guess produced in the laboratory, is not so good when it becomes a realised train operating on the railway. The translation, from proposition to realised train, is not a straight line and passive process. The winning proposition, produced in the decision-laboratory, is translated by a “flow of intermediaries” (Callon, 1998, p. 17) engaged in an active process, whereby they “translate their various and contradictory interests” (Latour, 1999, p. 311) in a social process that acts until the realised train finally emerges.

The elongated nature of modern procurements amplifies the opportunity for translation changes to be introduced between the winning proposition of a train and the realised train. Contracts were awarded for Thameslink and Crossrail in 2013 and 2014, respectively. The first trains did not appear in service until approximately three years after the contract was awarded. Signed contracts do not isolate this process of producing trains from a wider world. During this time, a General Election and change of Government took place in 2015. In addition to major events, such as this, there would also be a myriad of smaller changes: different staff involved as the train moves from sales to manufacturing; changes of personnel in many organisations; changing legislation; shifting patterns of housing, work and flows of people; and more.

Problems with realised trains arise because changes are introduced during the translation process, but there can also be problems that are only discovered when the realised trains are in use. A best guess is produced by, and in, the decision-laboratory. However, the modelled railway environment, within the decision-laboratory, is not the real railway on which the realised trains will operate. A proposition of a train may perform ideally on the modelled railway, within the decision-laboratory, but the realised train and real railway may reveal problems. An example follows to illustrate this.

The DfT's InterCity Express Programme (IEP) was discussed briefly in Chapter 3. It is a strategic decision to replace ageing InterCity services on the East Coast and Great Western lines. A consortium, led by Hitachi, was awarded the contract in 2012. Class 800 electro-diesel hybrid trains first entered service on the Great Western Railway in 2017, with Class 801 EMUs on the East Coast Main Line from 2019. However, Electro Magnetic Compatibility issues have been discovered (Ford, 2018b, pp. 38–39, 2018c, pp. 30–33), with the train's onboard electrical systems causing electro-magnetic interference with track-side control systems. One solution to this problem was to *choke*, or suppress, the interference by carrying c. 1½ -2 tonnes of copper onboard the train.

This unintended outcome is likely to reflect an inaccurate electric model of the trains and railway systems. The propositions of trains, and the modelled electrical railway, presumably did not produce electrical interference, but the realised train and the real electrical railway did. It is possible that translation problems, as explained above, have introduced changes in the electrical configuration of the realised train to cause this problem. However, this has not been evident in any discussion of this issue in the industry press. Rather, it seems that the decision-laboratory has inaccurately represented the real railway. If computer models were used to test electrical compatibility between train and track, then this could be the source of the problem and an area for subsequent improvement. However, there are many other possible explanations, because the decision-laboratory is ultimately trying to model the socio-material reality of the railway. For example, electrical interference could be eliminated by making changes to the track-side control systems, but this would incur costs for Network Rail, as the infrastructure manager. Alternatively, interference could be, and was, addressed by making changes to the onboard electrical systems, but this incurs costs for the train manufacturer (Hitachi) and train operators. There are real incentives not to carry these costs, with train manufacturers and operators likely to be keen for Network Rail to pick them up, and vice versa. Such incentives play a very real role in the socio-materiality of the railway and, in theory, this should be represented in the modelled railway created within the decision-laboratory.

The IEP procurement is a complex strategic decision that cannot be explored in the detail it deserves here. However, our decision-laboratories should aspire to accurately reflect the railway – in its electrical, commercial, and other forms. In this example, the gap between models and reality is evident in the form of 1½ -2 tonnes of copper. If this extra weight continues to be carried on the new Class 800 trains, then this will increase energy usage, cause additional damage to the track, and increase maintenance costs. These excessively heavy trains might have been addressed with propositions produced in a more articulate decision-laboratory.

To conclude, our models help us to produce a best guess. The example with electrical interference illustrates how the articulation of propositions can be discovered to be lacking. This is because our models can never be reality and, in effect, “all models are wrong” (Box, 1976, p. 792). Abstraction and simplification is essential to strategic decision-making, but we should “seek simplicity and distrust it” (A.N. Whitehead quoted in Stcngers, 2011, p. 104). Although this challenge presents an unbridgeable gap – between models and reality – improvements can still be made, as will be discussed later.

7.3.2 Trains are performative technology

The first challenge for strategic decision-making highlighted the unbridgeable gap between models and reality, whereas this second is driven by the ability of models to become reality. To explore this, I will first revisit some of the limitations of the metaphor of a decision-laboratory discussed in Chapter 2.

The production of propositions of new trains is not like a scientist trying to discover a world *out there*. The collective effort within the decision laboratory produces a proposition, which will later be translated into a realised train, and hopefully it is proven to be a good outcome. The decision laboratory may not necessarily relate to an existing world, but how the world will be, or even how the world should be. For example, the Crossrail propositions ran on infrastructure that could accept power returned by their regenerative braking. In this case, the propositions of a train produced in the Crossrail decision laboratory would not work in the current *real world* but should work in a future *real world* when it is translated into its realised form. If improvements to the Crossrail electrical infrastructure were delayed, then the Class 345 trains would not be able to return power generated by their braking. However, the Class 345 trains could act to make sure these improvements were delivered – even if this were delayed. The capability of this trains would act upon the infrastructure.

There is an aspect of the decision laboratory that is not about passively speculating about a world out there but is more about actively creating and changing the world out there. It is possible for propositions, when they are translated, to change the real world "in a way that fitted the model" (MacKenzie and Millo, 2003, p. 137). For example, if a new train service is developed between town A and town B, based upon an expectation of growth in town A and B, then the new line contributes to making that growth happen – this growth is (partially) enacted by the train service which has provided additional transport capacity.

The first challenge explored the problems that can be discovered because of the gap between models and reality. This second challenge relates to the performative nature of technology, such as a train, which can influence and change this real world in which they will operate. This challenge is not like the problem with electro-magnetic interference described above. Electricity and electrical systems do not negotiate, or compromise, and so problems are likely to be quickly identified. Unlike electrical interference there can be a *feedback lag* to discover problems. To a certain extent, especially where there are no alternatives, people will use whatever trains are produced, but that does not mean they are 'good' trains. Problems can be discovered later, as frustration grows, or inadequacies are revealed. An example from the Thameslink procurement can illustrate this challenge in action.

As discussed in Chapter 6, the Thameslink Class 700 trains produced by Siemens have been criticised for their *ironing board seats* (Graeme Paton, 2018). The same accusation has also been levelled at the new Class 800 trains (Horton, 2018), produced in the InterCity Express Programme. We know that comfort was part of the articulation of propositions within the Thameslink procurement. The Train Technical Specification, created by DfT, included five requirements relating to ride quality, including TTS 8.4.1 which stated the *ride quality shall achieve a mean comfort index of 2*.

An unexpected outcome of uncomfortable seats could be viewed as an example of the treachery of models described in the previous challenge. Uncomfortable seats in the realised Class 700 trains could reflect a problem with the comfort index, used in the articulation of propositions. Maybe this model of comfort was not close enough to *real* comfort. In line with this thinking, research has been commissioned (RSSB, 2019) to improve the seat selection process. This is valuable research, but I believe that this example illustrates a separate and distinct challenge for strategic decision-making.

This problem with seat comfort might not have come to attention as a problem. Unlike electro-magnetic interference, this problem might have been masked by other entities in the actor-network that makes up the railway service. People might have simply accepted this new reality and adapted. Passengers are part of the railway service and they can adapt, where electricity cannot. The flexibility of people and social systems allows them to adapt and fit the proposition. The railway industry might have argued that passengers were in the 'wrong', and the seats are comfortable, or that it is only an unrepresentative group that have a problem. These seats might have been accepted as comfortable, and it is likely to be true that not all people thought they were a problem. However, sometimes this flexibility can snap, and what was acceptable before, is no longer acceptable.

The second challenge for strategic decision-making recognises that the actor-network that acts as a train is performative, and it can bring about "different realities" (Law and Allaskuvla, 2019, p. 9). People and social systems can be changed by trains, but this has limits. Ideas and assumptions embodied in the train can be discovered to be 'wrong', or at least problematic. With discretionary travel this could manifest through alternative travel choices, but where there is no realistic alternative, then we might expect anger, frustration, and disappointment in the new trains and service.

If strategic decisions are trying to produce a best guess for a good train, then we need to recognise the adaptability of people and social systems that can mask a poor outcome. In other words, people may suffer in relative silence and that is a challenge for strategic decision-making if we want to articulate the best propositions of trains.

7.3.3 Society in the making

The first challenge for strategic decision-making derives from the gap between propositions and reality. The second reflects the performative nature of propositions that can create different realities in the social world. The third challenge arises because "'society' is an ongoing achievement…[and] in the making" (Callon, 2001, p. 62). This means that the definition of what is a 'good' train can shift. The extended duration of the actions to produce new trains exacerbates this problem. A good outcome at the start of the strategic decision, may not be the same when the trains finally enter service. Needs and requirements can shift, and so the articulation taking place within the modelled decision laboratory can diverge from an evolving social reality. Examples from the Thameslink and Crossrail procurements can illustrate this challenge.

Thameslink made "the procurement blunder of failing to specify charging points for mobile devices" (RAIL Opinion, 2017, p. 57), with USB charging increasingly prevalent in cars and public transport. When procurement began in 2008, this was perhaps not as common, but by the time the trains entered service, in 2016, this omission became more obvious. For trains that are seeking to encourage people away from their cars, attributes like this are an important part of the experience.

The Crossrail procurement provides a more significant example of this challenge. The location for the manufacture of the new trains became a critical issue during the Crossrail strategic decision, but this not the case at the start. This change occurred after Siemens was awarded the Thameslink contract, and Bombardier's Derby factory faced potential closure. In this case, the Crossrail procurement was updated for revised procurement guidance from the Treasury, and propositions of trains were then articulated with this new societal recognition of the wider costs and benefits associated with the production of new trains.

Propositions and models are how we make decisions about the future. Sometimes the goalposts shift, and do not turn out as expected, because society is constantly in the making. Over the 35-year life of a new train, this challenge is even more pronounced. The impact of the third challenge upon the new Class 700 and Class 345 trains will be determined over time, but a modelled standing capacity of *4 persons per m2*, used in both procurements, looks out of place in the 2020 world of social distancing and the COVID-19 crisis. This is a challenge for all railways and mass transit systems however, and it remains to be seen how they operate in a post-COVID reality.

7.4 Improving strategic decision-making

Making strategic decision to produce new trains is not easy. As discussed in Chapter 5, even the involvement of one of the greatest engineers of the time, I. K. Brunel, led to the production of “an extraordinary collection of freak locomotives,” (Adams, 1993, p. 114). The previous section explored three challenges common to all strategic decisions, and the outcomes they produce.

Firstly, the proposition of a train is not the realised train (the treachery of models), and so problems can arise because of changes discovered after the translation process. Secondly, problems with realised trains can be masked because humans are adaptable (trains are performative technology) and they can compensate for, or simply put up with, inadequacies in the outcome produced. The third challenge for strategic decision-making is because the future is unknowable (society in the making), and so a good outcome at the start of this process, may not be the same over time, especially given lengthy decision-making processes and the 30–35-year operating life of a train. These challenges will continue to contribute to unexpected, unintended, and undesirable outcomes. The following describes ways in which strategic decision-making can be adapted in response to these challenges.

Improvements in strategic decision-making to produce new trains could be identified within the translation stage when the proposition is translated into the realised train. However, this is beyond the scope of this research, which has focused upon the procurement process, from early problematisation through to selection of a winner. The procurement occurs within the decision-laboratory – a valuable *place* that brings actors together in a collective action to experiment, model, measure, discuss, interact, explore uncertainties, and speculate about new trains that will carry passengers in the future. These important *places* should be a focus for improving strategic decision-making.

What follows are three ideas to improve the effectiveness of decision-laboratories. The first relates to **prioritising the objectives** of the strategic decision and the desired outcomes that are to be achieved – this is about clarifying what the decision-laboratory is being asked to produce. The second focuses upon improvements to support **deliberate articulation** of propositions within, and by, the decision-laboratory – this is about recognising the laboratory as a site of active articulation of propositions to achieve the given objectives, rather than a neutral and passive place. The third improvement argues that the design of the decision-laboratory should also support some activities, that are described here as **exploratory articulation** – recognising the potential value of unplanned, unforeseen, and unexpected articulations that may be discovered to be useful.

7.4.1 Prioritising the objectives of the strategic decision

A decision-laboratory can produce propositions of trains, with many different attributes, that could all act as trains in different ways. This research has always appreciated that there are many other attributes of trains – beyond the focus here upon weight and the number of seats. Passenger trains take people from A to B at specified times punctually. Other attributes include the passenger experience, cost, comfort, safety, speed, and more. The Crossrail strategic decision added other desirable attributes. An articulate proposition of a train now placed more emphasis upon the wider social and environmental benefits to support the economy and local communities.

Different views have existed for a long time regarding the desirable attributes of trains and the railway. As discussed in Chapter 5, a 19th century trader in Berwick wanted his fish to be carried at half rates and did not care whether it paid the railways or not. During two World Wars the railways were managed to support the war effort, with a focus upon efficiency, maximising loads (freight and passenger) and eliminating unnecessary trips. Dr. Beeching saw the need to reduce uneconomic services, but later the Public Sector Obligation (PSO) grant was given to BR to compensate for these *socially necessary* loss-making services. Chapter 5 explores these developments over time.

Despite developments in the mechanisms by which the Government provides overall support to the railways, expectations of the railways at the level of strategic decisions can still be as vague as those placed upon British Railways to "'help energy conservation', 'get traffic off the roads' or 'help preserve the environment'" (British Railways Board, 1976, p. 23). Although there can be win-wins around environmental, social, and economic outcomes, we also know, from Chapter 2, that trade-offs are real, and it is often managers (public and private sector), who are left to resolve these uncertainties. This may be the best approach, with managerial judgement applied to specific actions, within a broad and open set of expectations set by Government. However, I think there is an argument for a more explicit **prioritisation of objectives**.

Chapter 6 showed that each strategic decision described various objectives and desired attributes for the new trains. The scoring attached to attributes of the trains described in the TTS documents is effectively a form of prioritisation – higher scores are effectively prioritised over attributes with lower scores. These two strategic decisions both include government (DfT and TfL) and so this could be viewed as Government specifying a prioritisation for the type of trains that it wants. Government bodies will not always be involved in these strategic decisions however and so, in these occasions, it may be necessary to clarify a prioritisation of objectives before the strategic decision begins.

Clarity of objectives is important because decision-laboratories are active sites in the articulation of propositions. For example, Eurostar trains, operating between London and Paris, were required to “offer more space and greater comfort than an A320 Airbus” (Walmsley, 2017, p. 44). Eurostar was seeking to compete with flights between London and Paris, and so this clear guidance would inform the articulation of propositions so that they did not maximise capacity at the expense of legroom and service. Other strategic decisions, such as new trains for rural railways, may not be competing with planes, but they may be aiming to encourage people out of private cars. These different objectives effectively mean that the Airbus A320 and modern cars, are *brought into* the decision-laboratories articulating propositions of new trains.

This prioritisation of objectives may not be necessary at the start of every strategic decision, and it might be sufficient to produce archetypal objectives for, say, intercity, rural, and commuting services. Clearly prioritising the objectives of strategic decisions could help to guide how the decision-laboratory articulates and produces propositions.

7.4.2 Deliberate articulation of propositions

The previous improvement to strategic decision-making focused upon the prioritisation of objectives **provided to** the decision laboratory. This improvement focuses **within** the decision-laboratory – the *place* where propositions are actively produced and articulated.

In a competitive situation, like Rainhill, Thameslink and Crossrail, the decision-laboratory should aim to produce several well-articulated propositions from which it is difficult to identify the most articulate. This is described here as **'deliberate articulation,'** because it recognises that the laboratory is active in the process of articulation. If the laboratory excludes something, or prioritises one attribute over another, then this will play an active role in the articulation of propositions. If we improve the effectiveness of the decision-laboratory, then we improve propositions.

The first way to improve decision-laboratories is to learn from mistakes. As realised trains enter service then feedback begins to accumulate and areas for improvement are discovered. The problem of uncomfortable seats on the Thameslink trains provides an example of this in action. The Train Technical Specification required propositions to achieve a *mean comfort index of 2* (TTS 8.4.1), using research and standards produced within the railway industry. The Thameslink procurement recognised the importance of comfort in the production of propositions, and comfort was deliberately designed into the laboratory's articulation process. However, as discussed in Chapter 6, problems with seat comfort have been discovered in the realised Class 700 trains. The discovery of this problem means that the ways of articulating comfort within the decision-laboratory can be reviewed, and ideally improved for next time. This has been the case for seat comfort, with new – and hopefully improved – guidance (RSSB, 2019) issued for seat selection in future strategic decisions.

Feedback can help to improve future strategic decisions, but the aspiration should be for the decision-laboratory to produce propositions that do not have such problems in the first place. To explore this, I will look at how comfort, in this case, is brought into the decision laboratory to articulate propositions.

A comfort model *represented* passengers (loop 4, public representation) and their comfort in the Thameslink procurement. However, seat comfort can be articulated, and brought into the action shaping propositions, in different ways, as illustrated in Figure 7.2 below.

Minimum seat comfort requirements

Seat Height	440mm +0 / -15mm
Seat Depth	435mm +0 / -5mm
Seat Width (distance between armrests)	460mm
Seat Width (for longitudinal seating)	555mm
Backrest Width	525mm
Armrest Height	240mm
Underside of headrest to seat	670mm
Point of contact, nape of neck	590mm – 756mm
Angle of seat	-8° to -15°
Angle between seat and back	95° to 105°
Legroom. Airline arrangement	695mm
Legroom. Bay seat arrangement	1390mm

Legroom clearance under tablet	650mm +/- 5mm
Legroom clearance under table	200mm
Seat Pad – Minimum thickness	50mm
Back Pad – Minimum thickness	25mm
Seat pad hardness – 500N force	40% compression
Seat pad hardness – 1100H force	70% compression
Long term seat durability	5% deformation after 50,000 cycles
The seat will look comfortable	
The seat will look attractive	
The seat will be comfortable to sit in	

Figure 7.2 Testing train seats for comfort in 1922 and in 2019

Source: (Robertson, 2005, p. 26; RSSB, 2019, p. 8)

Figure 7.2 shows the testing of seats for a passenger train in the 1920s (top) using, what I will describe here, as the *knee method*. Below the image of the *knee method* is a summary of the revised guidance on seat selection (RSSB, 2019) discussed earlier. Both methods are ways to measure and articulate comfort within the laboratory environment. The image shows that there are different ways of articulating comfort within a decision-laboratory. Other ways to articulate comfort could involve direct passenger feedback with trials of seats. There are various ways in which the decision-laboratory could be designed to articulate comfortable seats. I propose here that option that is **most representative** should be selected. This is not simple to discern, but there are risks that need to be managed.

In such complex technical actions, like the production of new trains, there is a risk that the value of public involvement is too easily dismissed or relegated. An unstated *ordering of knowledge* (Mol and Law, 2004, p. 44) can privilege some actors and practices over others. The updated comfort method for 2019 is more socially networked (Kofman, 2018) than the knee method of the 1920s. The 2019 comfort method has various actors, such as the Rail Safety and Standards Board, mobilised around it and connecting it to other industry practices. This does not mean it is 'better' than the knee method, but it is strengthened by these social connections that reach out and connect it to other actors.

As discussed in Chapter 2, in the past decision-makers consulted oracles and sacrificed animals. This thesis does not argue for a return to such methods! However, given that these strategic decisions are focused upon passenger trains, then the risk of inadequate representation of the public should be carefully monitored. **Representation matters** if we are seeking to create a rich experimental environment which represents the future operating environment of the realised trains. This representation can take many forms, but to "speak for others is to first silence those in whose name we speak" (Callon, 1984, p. 14). Passengers will remain the ultimate arbiters on the effectiveness of this representation.

The decision-laboratory is a valuable *place* for experimentation and articulation of propositions of trains. The three challenges for strategic decision-making mean that problems will still arise when these propositions are translated, but these *places* can be improved through **feedback** when problems are discovered. Attempts to avoid problems in the first place should focus upon the **representativeness** of the decision-laboratory. The five loops can help to consider how the decision-laboratory reaches out to the wider society in which the realised trains will operate.

7.4.3 Exploratory articulation of propositions

This third improvement of strategic decision-making introduces a tension with the previous idea of *deliberate articulation*. The metaphor developed in Chapter 2 described the experiments taking place at Rainhill, Thameslink, and Crossrail, as a metaphorical decision-laboratory. The metaphor of a factory was rejected because this action is not *producing the same widget again and again*, rather there is uncertainty regarding what is a ‘good’ train, which is translated from the most articulate proposition produced within the decision laboratory.

This idea introduces a slight modification to the understanding of what makes an articulate proposition. Building upon the work of Isabelle Stengers and Vinciane Despret (1993; Despret, 1996, 2004; Stcngers, 2011), Latour posits that **an articulate proposition is interesting**, compared to a bad articulation that is "‘Boring’, ‘repetitive’, ‘redundant’, ‘inelegant’, ‘simply accurate’, ‘sterile’" (Latour, 2004, p. 215). Therefore, I propose that a decision-laboratory should produce **articulate propositions that are interesting.** I will now explore what this means using a counter-example to show the risks of uninteresting and sterile propositions.

Both Crossrail and Thameslink included a Train Technical Specification (TTS) as part of the action to produce propositions of trains. Among the many detailed requirements that were *deliberately articulated* by Crossrail was TTS 3.40.3.1, which described the facilities required within the driver’s cab, including the need for *two coat hooks*. I do not know, but it is likely that these two coat hooks *represent* train drivers in this action, bringing in their views on the design of cabs, and problems that they encounter with other train cabs. Chapter 6 describes in detail how competing propositions were assessed, but, for here, it is sufficient to say that the requirements for the driving cab attracted a weighted score as part of the overall *Train Works* assessment. The coat hooks attracted a tiny part of the overall score, but they are there, nonetheless. It is reasonable to assume that Siemens, Bombardier, CAF, and Hitachi, all produced propositions of trains that had two coat hooks. If this is the case, the decision-laboratory has in many ways worked well. The propositions of trains are articulate to the needs of drivers. Of course, there is unlikely to be any need for experimentation with coat hooks and this potentially raises a challenge regarding the metaphor of a laboratory. It could be argued that the procurement of new trains is more like a hybrid of a factory and laboratory, with this example illustrating the factory component. However, I propose, that this small example, illustrates the risk of a decision-laboratory that loses too much of the hissing, spitting experiments that were clearly taking place at Rainhill. A decision-laboratory that becomes too constraining, specific, and directive regarding the action taking place, is **potentially producing a *contractual train*, rather than an interesting and articulate proposition of a train.**

A desire can easily arise during a procurement, to specify in detail what is required. This can be based upon good intentions, such as managing the risks associated with the later translation stage. If two coat hooks for the driver's cabin were specified as a mandatory requirement (this was not mandated in the Crossrail procurement), then the chance of getting two coat hooks in the realised trains is greatly improved! Similarly, specifying that 3+2 seating is forbidden, avoids the risk of giving a seat count target that may be met by squeezing in seats to get a higher score in the assessment. In the collective action to produce propositions of trains, there is a risk that Bidders adopt an attitude of 'give them what they want,' which would lead to articulate propositions, in the sense of connecting to specific requirements, but the ambiguous, exploratory, and exciting, nature of the decision-laboratory becomes lost. The **propositions produced could be articulate, but dull**. To maintain, or introduce, more experimental and *exploratory articulation* of propositions I suggest there are two key considerations, which I describe as *letting go*, and *bringing in*. The idea of *letting go* will be explored first.

Decision-laboratories can support many possibilities for articulation of propositions, but this requires those in charge to *let go* and allow surprises to happen (de Laet and Mol, 2000, p. 250). To support the process of exploratory articulation, those in charge must "jeopardize this privilege of being in command" (Latour, 2004, p. 216), and view their role as active participants in a collaborative action.

The Trials at Rainhill illustrated a willingness to adapt the rules in aid of exploratory and unforeseen articulation. The assignment of a load to competitors, was based upon a **prior view** of a locomotive, that included a tender car to carry fuel and water. Stephenson's *Rocket* had a tender car, but *Novelty* did not fit this model. The judges at Rainhill exercised their judgement and allowed the stipulations and conditions to be modified and reissued. The laboratory was adapted to allow new articulations of how a locomotive acted. Similarly, *Sans Pareil* was too heavy, and did not have the required six wheels for its weight, but it too was permitted to run. Although *Sans Pareil* failed, the Trials were more *interesting* for its involvement, and the success of Rocket could be viewed more confidently, because it was connected to a wider performance that demonstrated the limitations of other propositions.

The Judges at Rainhill did not act as isolated and removed observers of experiments, rather they were active participants enriching the laboratory environment, to support the creation of interesting and articulate propositions of trains. The Judges were part of a collective effort at Rainhill. *Rocket* was a success, and the willingness of the Judges, and others, to take some risks and adapt the laboratory played a part in that outcome.

In the case of Thameslink and Crossrail this idea of *letting go* could involve a reduction in the levels of specificity, and deliberate articulation, undertaken by DfT and Crossrail, although this needs to be recognised for the risky endeavour that it is. A desire to produce interesting and articulate propositions of trains has a tension with the desire for accountability, especially where public monies are involved. There may be occasions when we know exactly what we want from new trains, and so very precise requirements are appropriate. However, **if we want interesting and articulate propositions of new trains, then this involves taking some risks and allowing room for exploratory articulations.**

In addition to *letting go*, more interesting and articulate propositions can be encouraged by deliberately *bringing in* actors that can produce unforeseen opportunities to make propositions more articulate and interesting. Rainhill provides an example to explore this idea.

At the time of the Rainhill trials, locomotive engines were a shock to the public, making a fearful noise and smell. However, the Trials provided a grandstand for the public that allowed them to see, hear and smell these new creations. The organisers took a risk that the public might reject these new temperamental creatures. A desire to demonstrate the safety of the new technology could have been achieved in other ways. This may have been a calculated risk, given the earlier success of the Stockton and Darlington Railway (Chapter 5), but it was still a risk. The public were not an official part of the judging, but they are part of the action. The Trials, and the articulation of propositions, effectively continued after the award, when Stephenson took excited groups for rides at speed. This was not required for the competition, but the cheering and excited crowds hauled by *Rocket* would provide further reassurance to Stephenson, and the Directors, that the railway would be a success. These additional rides provided further opportunities for objections, or new articulations, to be identified.

Bringing in the public like this was risky, but bringing the public into the action at Rainhill, is also bringing in the public's experience of canals and roads – the main competitors at the time to locomotives. The public can experience the noise and smells of the locomotives, but also their superior speed compared to road and rail. Stephenson's *Rocket* was the most articulate at the Trials, and could achieve what was required in the experiments, but the cheers from the grandstand are evidence that it was also an interesting and articulate proposition to the public.

The later procurements at Thameslink and Crossrail were no longer competing with canals and stagecoaches on rutted roads. The example of Eurostar, given earlier, illustrates how planes were brought into that action. The "A320 Airbus" (Walmsley, 2017, p. 44) was effectively brought in because Eurostar was seeking to compete with flights between London and Paris, and so legroom and comfort was to be articulated with this airplane.

Actively bringing in other actors to the decision laboratory is worthy of consideration to produce more articulate and interesting propositions. Railway engineering and professional expertise (loop 2, autonomization) is understandably privileged when considering many aspects of the safe design of trains. The idea here is that propositions of trains can be made more interesting by integrating insights from passengers "alongside or on top" (Mol and Law, 2004, p. 44) of knowledge from other actors. Passengers and the public have been explored here, but other communities of interest could introduce unexpected and unforeseen articulations that could potentially strengthen propositions. It is claimed that including *concerned groups* affected by strategic decisions can lead to more successful outcomes (Flyvbjerg, Rothengatter and Bruzelius, 2003, p. 89), providing they are involved in a constructive role. Such groups are part of the success of a train and railway, especially when they become passengers.

7.5 Further work

The InterCity Express Programme (IEP) has been referenced briefly in this research and would be worthy of more in-depth analysis. IEP was a complex strategic decision, like Thameslink and Crossrail, that also involved the DfT and many of the same actors. IEP was awarded to Hitachi Trains in 2012, and the realised trains are now mostly in service, therefore it is possible to assess the outcome of the strategic decision, using the attributes of the trains. In particular, the **IEP is of interest because, in addition to electrically-powered trains, it also produced bi-mode trains.** The bi-modes carry both diesel and electric engines that collectively act to provide flexibility for the train to travel on parts of the network that are not electrified. This flexibility is at the cost of potentially increased weight to carry different engines, as was suggested by the empirical analysis (Figure 4.14) in Chapter 4. Electrifying the network and running electrically-powered trains would have been an alternative approach, but reports suggested that this was too costly. Bi-modes allowed an onboard power supply (diesel fuel and engines) to be substituted for a programme of electrification.

Another area for further research, that was also referenced earlier, would be to focus upon **the translation of propositions into realised trains**. This begins with the selection of a winning proposition of a train and concludes with the realised train carrying passengers on the operational railway. It would be interesting to determine if there are examples of lightweight propositions of trains that are produced within the decision-laboratory, but when translated they *become* heavy trains. There are many translations that take place after the identification of a winning bidder, which might explain such an outcome. Research could focus upon the contracting process, that takes place between the contracting body (e.g., DfT) and the winning Bidder (e.g., Siemens). The commercial sensitivity of these interactions would present a methodological challenge, as discussed in Chapter 3 regarding the new Merseyrail trains. Changes in translation can also be introduced because of organisational changes within the winning bidder and its partners, as the organisations move from sales to delivery with changes of personnel and processes. Translation changes could be introduced after the train leaves the factory. The manufactured trains must still go through acceptance processes for the train to be accepted onto the railway.

Beyond rail it would be interesting to apply this thinking to **strategic decisions in other sectors and situations**. The theory developed here could be usefully applied to building bridges, developing new products, research and development, and many other settings. Strategic decision-making involves models, abstractions, and propositions, with the most articulate proposition then translated and realised. For example, the network of resources that act as a bridge is as fluid as a train. There are many ways to configure socio-material collections of resources so that they collectively act as a bridge. Different conceptions (loop 5, links and knots) of the bridge and its purpose (Winner, 1980; Joerges, 1999) will draw in and arrange resources in different ways. They might all span a gap between two points, but they will all have different attributes. The theory developed here, using ANT and the five loops, can help to provide a richer understanding of strategic decision-making, and the heterogenous resources that are assembled to act.

The final area that I think would be interesting for further research relates to blame and accountability. There is often a strong social desire to find a smoking gun and someone to blame when things go wrong, whether that is heavy trains or any other problematic outcome. However, heavy trains are not so much someone's mistake, but are more like a "collective drift of good intentions" (Latour, 1996, p. 290). ANT's distributed view of agency can "jeopardise attempts to hold individuals responsible for their actions" (Bennett, 2005, p. 452). The desire for accountability can be particularly strong when it comes to large public projects. It would be interesting to understand **how a distributed view of agency interacts with a desire for accountability, and simply blame.**

7.6 Concluding remarks

Heavy trains were the frustrating starting point for this research because of the environmental implications of this outcome. The goal was to understand how this could have happened, and how it could be improved in the future. There will be many other strategic decisions that begin with good intentions of what they will deliver, but somewhere along the way this gets lost. Unintended and unexpected outcomes are a sign of strategic decision-making that maybe could have been managed better.

This research has demonstrated that trains and railways are dynamic and fluid concepts, even when made of iron and steel. Heavy trains were not an inevitable outcome; they reflect one of many possibilities.

The *proposition* is a valuable concept to understand strategic decisions. Propositions exist within the world of models, abstractions, and simplification, which is essential for strategic decision-making. They allow us to speculate, experiment and, essentially, produce a *good guess*. When a proposition is translated and realised, we will discover if it was a good guess or not.

Propositions are produced within a *decision-laboratory*. This valuable social place brings together a collection of actors – human and non-human – in a collective action that articulates propositions. The winning proposition is the most articulate within the modelled and abstracted environment of the decision-laboratory. This proposition will be translated and realised, and we will discover if it was a good guess or not.

The ability to criticise and improve our abstractions is ”essential to the healthy progress of society” (A.N. Whitehead quoted in Stcngers, 2011, p. 130). **This thesis proposes that if we improve decision-laboratories, then we will improve strategic decisions and outcomes.**

On Monday 5th October 1829 a “hissing, spluttering” (Marshall, 1930, p. 1063) set of experiments began taking place, on a model railway track at Rainhill, near Liverpool. From these Trials the *Rocket* emerged as the winner and would operate successfully on the Liverpool & Manchester Railway – the world’s first inter-city railway. After this, railways expanded across the country and the world. Improving strategic decision-making does not require a grandstand for an audience, but it should be recognised as a collective action, with various actors in the foreground and background. The *place* in which strategic decision-making takes place can be considered as a decision-laboratory, that is **active** in the experiments taking place. The outcomes of our strategic decisions are not ordained by the movement of planets and other forces to be studied in a world out there. Nobody in this decision-laboratory said, ‘Make sure those trains are heavy.’ We should aspire to design, and manage, our decision-laboratories as well as they did at Rainhill.

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9 Appendices

A. Table of early railway companies created by Acts of Parliament in the 19th century.

Table 9.1 Early Railway Companies set up by Acts of Parliament in the 19th Century until the 1850s.

Source:(Wikipedia, 2017)

Scottish early railways	
Caledonian Railway	**(incorporated 1845)**
Caledonian Railway	**became part of the London, Midland and Scottish Railway on 1 July 1923 under the Railways Act 1921.**
Aberdeen Railway	opened in stages between 1848 and 1853
Brechin and Edzell District Railway	
Cathcart District Railway	
Crieff and Comrie Railway	authorised 1890
Crieff and Methven Junction Railway	opened 1867
Crieff Junction Railway	opened 1856
Dunblane, Doune and Callander Railway	incorporated in 1846
Dundee and Newtyle Railway	opened 1841 (incorporated in Scottish Central Railway)
Glasgow and Paisley Joint Railway	opened 12 August 1840
Glasgow Central Railway	opened 26 November 1894
Glasgow, Garnkirk and Coatbridge Railway	opened 1831 as the Garnkirk and Glasgow Railway
Glasgow, Paisley and Greenock Railway	opened 29 March 1840; merged with the Caledonian Railway 1847
Hamilton and Strathaven Railway	opened 6 August 1860; taken over by the Caledonian Railway 1864
Lanarkshire and Dunbartonshire Railway	authorised in 1891
Lochearnhead, St Fillans and Comrie Railway	opened Comrie to St Fillans 1 October 1901; opened to Balqhidder 1 May 1905

Perth, Almond Valley & Methven Railway	opened 1858
Scottish Central Railway (to Perth and Dundee)	formed in 1845
Scottish North Eastern Railway (to Aberdeen)	
Wishaw and Coltness Railway	
Independent Lines operated by the Caledonian Railway	
Callander and Oban Railway	opened 1 July 1880
Killin Railway	opened 13 March 1886
Lanarkshire and Ayrshire Railway	opened 1888
Glasgow and South Western Railway	**(title assumed 1850)**
Glasgow and South Western Railway	**became part of the London, Midland and Scottish Railway on 1 January 1923 under the Railways Act 1921.**
Ardrossan and Johnstone Railway	opened 6 November 1831; became the dual-tracked Ardrossan Railway on 23 July 1840
Bridge of Weir Railway	opened 1864
Glasgow and Paisley Joint Railway	opened 12 August 1840.[1]
Glasgow, Paisley, Kilmarnock and Ayr Railway	opened 12 August 1840
Glasgow, Barrhead and Kilmarnock Joint Railway	opened 29 September 1848
Greenock and Ayrshire Railway	opened 23 December 1869
Kilmarnock and Troon Railway	First railway in Scotland authorised by Act of Parliament, opened 6 July 1812; originally worked by horses, converted to steam operation in 1817
Maidens and Dunure Railway	opened 17 May 1906
Paisley and Renfrew Railway	opened 21 July 1835; Scottish gauge railway originally locomotive hauled, then down graded to horse operation. Reopened as dual track, standard gauge, line 1 May 1866.
Great North of Scotland Railway	**(incorporated 1846)**

Great North of Scotland Railway	**became part of the London and North Eastern Railway on 1 January 1923 under the Railways Act 1921.**
Aberdeen and Turriff Railway	
Alford Valley Railway	built 1859
Banffshire Railway	
Banff, Macduff and Turriff Extension Railway	
Banff, Portsoy and Strathisla Railway	
Deeside Railway	
Deeside Extension Railway	
Formartine and Buchan Railway	
Inverury and Old Meldrum Junction Railway	
Keith and Dufftown Railway	
Morayshire Railway	opened 10 August 1852
Strathspey Railway	
Highland Railway	**(title assumed 1865)**
Highland Railway	**became part of the London, Midland and Scottish Railway on 1 January 1923 under the Railways Act 1921.**
Dingwall and Skye Railway	opened 19 August 1870
Duke of Sutherland's Railway	opened 19 June 1871
Findhorn Railway	opened 18 April 1859
Inverness and Aberdeen Junction Railway	opened 18 August 1858
Inverness and Nairn Railway (INR)	opened 5 November 1855
Inverness and Perth Junction Railway	opened 9 September 1863
Inverness and Ross-shire Railway	opened 23 March 1863
Nairn and Keith Railway	opened 1858 amalgamated with INR 1861
Perth and Dunkeld Railway	opened 7 April 1856
Sutherland Railway	opened 13 April 1868

Sutherland and Caithness Railway	opened 28 July 1874
Wick and Lybster Railway	
North British Railway	**(incorporated 1844)**
North British Railway	**became part of the London and North Eastern Railway on 1 January 1923 under the Railways Act 1921.**
Ballochney Railway	opened 8 August 1828
Dundee and Arbroath Railway	opened 1831
Edinburgh and Dalkeith Railway	
Edinburgh and Glasgow Railway	opened 28 July 1863
Edinburgh Suburban and Southside Junction Railway	
Glasgow, Yoker and Clydebank Railway	authorised in 1878
Invergarry and Fort Augustus Railway	opened 1901
Kincardine Line	open to Kincardine in 1893, and on to Dunfermline in 1906
Monkland and Kirkintilloch Railway	first public steam railway in Scotland opened 1826
Newburgh and North Fife Railway	
Slamannan Railway	opened 31 August 1840
Stirling and Dunfermline Railway	opened progressively between 1850 and 1853
West Highland Railway	opened 7 August 1894 with an extension to Mallaig opened 1901.
English and Welsh early railways	
East	
Great Eastern Railway	
Eastern Counties Railway (ECR)	opened 20 June 1839; original 5 ft gauge converted to standard in 1845, absorbed into GER Aug 1862
Eastern Union Railway	incorporated 1844, opened 1846, absorbed 1847.

Eastern Union and Hadleigh Junction Railway	
Ipswich and Bury St Edmunds Railway	
Colchester, Stour Valley, Sudbury and Halstead Railway	incorporated 1846, opened 1848
East Anglia Railway	absorbed into Eastern Counties Railway, Jan 1852
Saffron Walden Railway	incorporated 1861, sponsored by ECR.
Northern and Eastern Railway	incorporated 1836 gauge conversion as with ECR
London and Blackwall Railway	opened 1840, extended to Tilbury with ECR 1854 (authorised 1852 as London, Tilbury and Southend Railway (LT&SR)), absorbed by GER 1866. Started with non-standard gauge, converted 1849.
Ely, Haddenham and Sutton Railway (later Ely and St Ives Railway)	authorised 1864, opened 1866, leased by ECR since opening, absorbed by GER 1897
Norfolk Railway	
Colne Valley and Halstead Railway	incorporated 1856
Harwich Railway	
East Anglian Railways	(the plural is correct!) formed by merger in 1847. Bankrupt in 1851, it was operated by arrangement by ECR until the takeover by GER.
Lynn and Dereham Railway	
Lynn and Ely Railway	
Ely and Huntingdon Railway	
East Suffolk Railway	(re-incorporation of the "Halesworth, Beccles and Hadiscoe Railway" in 1854), absorbed by ECR 1859
Yarmouth and Haddiscoe Railway	absorbed 1858
Lowestoft and Beccles Railway	absorbed 1858
Midland and Great Northern Joint Railway	incorporated 1893

Great Western Railway	
Great Western Railway	**incorporated 1835, opened London to Maidenhead Bridge 4 June 1838, completed throughout to Bristol 30 June 1841**
Hayle Railway	opened 23 December 1837, closed for rebuilding 16 February 1852, reopened by West Cornwall Railway
Cheltenham and Great Western Union Railway	opened Swindon to Cirencester 31 May 1841, opened throughout to Cheltenham 13 October 1847
Bristol and Exeter Railway	opened to Bridgwater 14 June 1841, completed in stages to Exeter 1 May 1844, amalgamated with GWR 1 January 1876
Cornwall Minerals Railway	opened 1 June 1874 replacing and connecting several earlier railways and tramways. Amalgamated with GWR 1 July 1896
Par Tramway	construction started c.1841, completed north of Pontsmill 1847, extended to Par Harbour 1855
Newquay Railway	authorised by Act of Parliament 1844, completed 1849
Lostwithiel and Fowey Railway	opened 1 June 1869, closed 1 January 1880, transferred to CMR 27 June 1893 and reopened 1893
Newquay and Cornwall Junction Railway	opened 1 July 1869, transferred to CMR 1 June 1874
Liskeard and Caradon Railway	opened 28 November 1844, vested in GWR 1 July 1909
Shrewsbury and Chester Railway	opened 4 November 1846, amalgamated with GWR 1 September 1854
South Devon Railway	opened 30 May 1846, completed in stages to Plymouth 2 April 1849, amalgamated with GWR 1 February 1876
Torquay branch	opened 18 December 1848
South Devon and Tavistock Railway	opened 22 June 1859
Dartmouth and Torbay Railway	completed 16 August 1864
Launceston and South Devon Railway	opened 22 June 1865
Moretonhampstead and South Devon Railway	opened 4 July 1866
Buckfastleigh, Totnes and South Devon Railway	opened 1 May 1872

Berks and Hants Railway	opened Reading to Hungerford 21 December 1847 and Reading to Basingstoke 1 November 1848; Berks and Hants Extension Hungerford to Devizes opened 11 November 1862
Wilts, Somerset and Weymouth Railway	opened Chippenham to Westbury 5 September 1848; completed in stages to Weymouth 20 January 1857
Shrewsbury and Birmingham Railway	opened 1 June 1849, amalgamated with GWR 1 September 1854
South Wales Railway	opened Chepstow to Landore 18 June 1850, Chepstow Bridge opened 19 June 1862, amalgamated with GWR 1 January 1862
Gloucester and Dean Forest Railway	opened 19 September 1851
Vale of Neath Railway	opened 24 September 1851, amalgamated into GWR 1 February 1865
West Cornwall Railway	opened 11 March 1852 including previous Hayle Railway, transferred to GWR 1 January 1868
Hereford, Ross and Gloucester Railway	opened 11 July 1853
Wycombe Railway	opened 1 August 1854
Abingdon Railway	opened 2 June 1856
Bridport Railway	opened 12 November 1857, bought by GWR 1 July 1901, closed 5 May 1975
Liskeard and Looe Union Canal	railway opened 11 May 1858, vested in GWR 1 January 1923
East Somerset Railway	first stage opened 9 November 1858, completed 1 March 1862
Great Western and Brentford Railway	opened 18 July 1858
Cornwall Railway	opened to Truro 4 May 1859, extended to Falmouth 21 August 1863, amalgamated with GWR 1 July 1889
West Midland Railway	formed 1 July 1860, amalgamated with GWR 1 August 1863
Oxford, Worcester and Wolverhampton Railway	opened at Worcester 5 October 1850, completed from Wolverhampton to Oxford in stages by April 1854
Newport, Abergavenny and Hereford Railway	opened 2 January 1851
Worcester and Hereford Railway	opened 25 July 1859

Ely Valley Railway	opened 1 August 1860
Midlands	
Manchester, Sheffield and Lincolnshire Railway	**(became Great Central Railway 1897)**
Great Central Railway	**incorporated 1897**
Manchester, Sheffield and Lincolnshire Railway: formed by an amalgamation of:	
Sheffield, Ashton-under-Lyne and Manchester Railway	
Sheffield and Lincolnshire Junction Railway	
Great Grimsby and Sheffield Junction Railway	
including Grimsby Docks Company.	
South Yorkshire Railway	opened 9 September 1854, merged with GCR 1 August 1864
Including southern part of Sheffield, Rotherham, Barnsley, Wakefield, Huddersfield and Goole Railway Company	
Wigan Junction Railway	
Wrexham, Mold and Connah's Quay Railway	
North Wales and Liverpool Railway	
Liverpool, St Helens and South Lancashire Railway	
Lancashire, Derbyshire and East Coast Railway	acquired in 1907
Midland Railway: formed 1844 by amalgamation:	
North Midland Railway	
Midland Counties Railway	
Birmingham and Derby Junction Railway	
Later acquired:	
Leicester and Swannington Railway	opened 14 July 1832

Sheffield and Rotherham Railway	1838
Birmingham and Gloucester Railway	opened 17 December 1840
Little North Western Railway (Skipton – Lancaster)	opened 1 June 1850
Manchester, Buxton, Matlock and Midlands Junction Railway	
North Staffordshire Railway	incorporated in 1845 to promote three railway schemes. Three Acts of Parliament on 26 June 1846 were given to the one company. Main line opened in 1848. Further Acts were all granted to the NSR Co. which remained independent until the 1923 Grouping.
North	
Maryport and Carlisle Railway	(first section) opened 1845. Remained independent until the 1923 Grouping
Furness Railway (Furness)	(first section) opened 11 August 1846
Ulverston and Lancaster Railway	opened 1857 amalgamated with Furness in 1862
Great Northern Railway	incorporated 1846
Edgware, Highgate and London Railway	incorporated 1862
London and York Railway	
Direct Northern Railway	
North Eastern Railway (NER)	incorporated 1854
York, Newcastle and Berwick Railway	was York and Newcastle Railway (1846–1847) and Newcastle and Darlington Junction Railway (1842–1846)
Durham Junction Railway	incorporated 1834, amalgamated with N&DJR in 1844
Brandling Junction Railway	incorporated 1836, amalgamated with N&DJR in 1845
Durham and Sunderland Railway	incorporated 1834, amalgamated with N&DJR in 1846
Pontop and South Shields Railway	incorporated 1842, amalgamated with N&DJR in 1846
Stanhope and Tyne Railway	incorporated 1834, amalgamated with P&SSR in 1842

Newcastle and Berwick Railway	incorporated 1845, amalgamated with Y&NR in 1847
Newcastle and North Shields Railway	incorporated 1836, amalgamated with N&BR in 1845
Great North of England Railway	incorporated 1836, amalgamated with YN&BR in 1850
York and North Midland Railway	incorporated 1836
Leeds and Selby Railway	incorporated 1830, amalgamated with Y&NMR in 1844
Whitby and Pickering Railway	incorporated 1833, amalgamated with Y&NMR in 1845
East and West Yorkshire Junction Railway	incorporated 1846, amalgamated with Y&NMR in 1852
Leeds Northern Railway	was Leeds and Thirsk Railway (1845–1849)
Malton and Driffield Railway	incorporated 1846
Deerness Valley Railway	incorporated 1855, amalgamated with NER in 1857
Hartlepool Dock and Railway	incorporated 1832, amalgamated with NER in 1857
North Yorkshire and Cleveland Railway	incorporated 1854, amalgamated with NER in 1858
Bedale and Leyburn Railway	incorporated 1853, amalgamated with NER in 1859
Hull and Holderness Railway	incorporated 1853, amalgamated with NER in 1862
Newcastle and Carlisle Railway	incorporated 1829, amalgamated with NER in 1862
Blaydon, Gateshead and Hebburn Railway	incorporated 1834, amalgamated with N&CR in 1839
Stockton and Darlington Railway	incorporated 1821, amalgamated with NER in 1863
Darlington and Barnard Castle Railway	incorporated 1854, amalgamated with S&DR in 1858
Middlesbrough and Guisborough Railway	incorporated 1852, amalgamated with S&DR in 1858
Middlesbrough and Redcar Railway	incorporated 1845, amalgamated with S&DR in 1858
Wear Valley Railway	incorporated 1845, amalgamated with S&DR in 1858
Bishop Auckland and Weardale Railway	incorporated 1837, amalgamated with WVR in 1847
Eden Valley Railway	incorporated 1858, amalgamated with S&DR in 1862
Frosterley and Stanhope Railway	incorporated 1861, amalgamated with S&DR in 1862
South Durham and Lancashire Union Railway	incorporated 1857, amalgamated with S&DR in 1862
Cleveland Railway	incorporated 1858, amalgamated with NER in 1865
West Hartlepool Harbour and Railway	incorporated 1852, amalgamated with NER in 1865

Clarence Railway	incorporated 1828, amalgamated with WHH&R in 1853
Stockton and Hartlepool Railway	incorporated 1839, amalgamated with WHH&R in 1853
Hull and Hornsea Railway	incorporated 1862, amalgamated with NER in 1866
West Durham Railway	incorporated 1839, amalgamated with NER in 1870
Hull and Selby Railway	incorporated 1836, amalgamated with NER in 1872
Blyth and Tyne Railway	incorporated 1852, amalgamated with NER in 1874
Hexham and Allendale Railway	incorporated 1865, amalgamated with NER in 1876
Leeds, Castleford and Pontefract Junction Railway	incorporated 1873, amalgamated with NER in 1876
Tees Valley Railway	incorporated 1865, amalgamated with NER in 1882
Hylton, Southwick and Monkwearmouth Railway	incorporated 1871, amalgamated with NER in 1883
Scotswood, Newburn and Wylam Railway	incorporated 1871, amalgamated with NER in 1883
Whitby, Redcar and Middlesbrough Union Railway	incorporated 1866, amalgamated with NER in 1889
Wear Valley Extension Railway	incorporated 1892, amalgamated with NER in 1893
Scarborough & Whitby Railway	incorporated 1871, amalgamated with NER in 1898
Cawood, Wistow and Selby Light Railway	incorporated 1896, amalgamated with NER in 1900
Scarborough, Bridlington and West Riding Junction Railway	incorporated 1885, amalgamated with NER in 1914
Lancashire and Yorkshire Railway	incorporated 1847. In 1846 the Liverpool and Bury Railway was amalgamated with the Manchester and Leeds Railway, which became known as The Lancashire and Yorkshire Railway in 1847
Manchester and Leeds Railway	incorporated 1836
Manchester and Bolton Railway	opened 1838
Ashton, Stalybridge and Liverpool Junction Railway	1844
Liverpool and Bury Railway	1845
East Lancashire Railway	opened 1846: a section of this line is now a heritage railway
Wakefield, Pontefract and Goole Railway	opened 1848
Liverpool, Crosby and Southport Railway	opened 1848

London and North Western Railway (LNWR)	formed by amalgamation in 1846, there were 45 formerly independent railways within the LNWR, including:
Liverpool and Manchester Railway	opened 15 September 1830
London and Birmingham Railway	(first section) opened 20 July 1837; opened throughout 17 September 1838
Grand Junction Railway	opened 1837
Chester and Crewe Railway	opened 1846
Chester and Holyhead Railway	opened 1848 to Bangor 1850 to Holyhead
Manchester and Birmingham Railway	
Lancaster and Carlisle Railway	
Cromford and High Peak Railway	
Kendal and Windermere Railway	
Watford and Rickmansworth Railway	opened 1 October 1862 closed 1998 possible reopening (see Watford tube station)
South	
Isle of Wight Central Railway	incorporated 1887, amalgamation of several smaller railways including:
Cowes and Newport Railway	incorporated 1859
Ryde & Newport Railway	opened 1875
Isle of Wight (Newport Junction) Railway	completed 1879
London Brighton and South Coast Railway	amalgamation of five railways August 1846:
London and Croydon Railway	incorporated 1835 opened 1839
London and Brighton Railway	incorporated 1837 opened 21 September 1841
Croydon and Epsom Railway	incorporated 1844.
Brighton and Chichester Railway	incorporated 1844.
Brighton Lewes and Hastings Railway	incorporated 1844.
West End of London and Crystal Palace Railway	opened 1856-8.

Victoria Station and Pimlico Railway	incorporated 1858.
London, Chatham and Dover Railway	
East Kent Railway	incorporated 1853
Victoria Station and Pimlico Railway	incorporated 1858.
Mid-Kent Railway	incorporated 1855.
London and South Western Railway (LSWR)	
London and Southampton Railway	opened (first section) 21 May 1838; renamed LSWR 1838
Bodmin and Wadebridge Railway	opened 23 May 1832, sold to LSWR autumn 1846 but not legally vested in that company until 1 July 1886
Richmond Railway	opened 27 July 1846
Windsor, Staines and South Western Railway	opened 1848/1849
Southampton and Dorchester Railway	opened 1 June 1847; extended to Weymouth 20 June 1857
Staines, Wokingham and Woking Junction Railway	opened 1856
Andover and Redbridge Railway	opened 6 March 1865, closed 1967
Lymington Railway	opened 12 July 1858, closed 1967
London, Tilbury and Southend Railway	incorporated 1862 amalgamated with Midland Railway 1912
London and Blackwall Railway	
Metropolitan Railway (MetR)	
North Metropolitan Railway	incorporated 1853; became MetrR 1854. Other sections followed in 1860–70
Midland and South Western Junction Railway: formed in 1884 by amalgamation of	
Swindon, Marlborough and Andover Railway	incorporated 1873
Swindon and Cheltenham Extension Railway	incorporated 1881
North London Railway incorporated 1846 original name:	
East and West India Docks and Birmingham Junction Railway	

Pentewan Railway	The railway from St Austell was complete by 22 June 1829 but not incorporated until 20 February 1873 as the Pentewan Railway and Harbour Company Limited. An Act of Parliament on 7 August 1874 authorised the use of locomotives. It was closed from 4 March 1918.
Redruth and Chasewater Railway	This was opened on 30 January 1826 and was locomotive worked from 1 December 1864. It was closed from 27 September 1915.
Somerset and Dorset Joint Railway (S&DJR). An amalgamation of the:	
Somerset Central Railway	first section opened on 1 November 1860, and
Dorset Central Railway	first section opened on 28 August 1854.
The S&D Joint Railway	was jointly operated by the Midland Railway and the London and South Western Railway (L&SWR). After the 1 January 1923 Grouping, joint ownership of the S&DJR passed to the LMS and the Southern Railway.[1]
South Eastern Railway	incorporated 1836
London and Greenwich Railway	
Canterbury and Whitstable Railway	
Mid-Kent Railway	incorporated 1855.
Reading, Guildford and Reigate Railway	
Surrey Iron Railway(SIR)	opened 1804 (4 ft gauge):
Croydon Merstham and Godstone Railway – extension of SIR	
West Somerset Mineral Railway	incorporated 1855 to carry iron ore; passenger service from 1865; closed to all traffic 1898 see article here
Wales	
Cambrian Railways	incorporated between 1864 and 1904
Oswestry and Newtown Railway	30 miles: incorporated 6 June 1855; opened 1860-1

Llanidloes and Newtown Railway	12 1/4 miles: 4 August 1853; 1859. Until 1861 this section of the line was completely isolated
Newtown and Machynlleth Railway	23 miles: 27 July 1857; 1863
Oswestry, Ellesmere and Whitchurch Railway	18 miles: 1 August 1861; 1863-4
Aberystwyth and Welsh Coast Railway	86 miles: 26 July 1861; 1863–69
Mid Wales Railway	45 1/2 miles: 1 August 1859; 1 September 1864. This Railway maintained complete independence from the Cambrian until 1 January 1888, when the latter took over working the line; and on 1 July 1904 when the two Railways amalgamated.
and several railways opened in the 1860s	
Festiniog Railway	incorporated 23 May 1832 (1 ft 11 1/2 in (597 mm) gauge) ?13 1/2 miles opened 1836 to carry dressed slate from Blaenau Ffestiniog to Porthmadog for export by sea, carried passengers from 1865. Still independent and since 1954 a leading heritage railway.
Llanelly Railway and Dock Company	incorporated 1828
Rhymney Railway	incorporated 1854
Taff Vale Railway (TVR)	incorporated 1836. Among the eight railways amalgamated with the TVR is one early railway:
Aberdare Railway	opened 1846

B. The Grouping of Railways. Reorganisation of Railway System, Railways Act 1921

Table 9.2 Reorganisation of Railway System 1921. Grouping of Railways.

Source: (His Majesty's Government, 1921, pp. 69–72)

Group	Constituent Companies	Route km
1. The Southern Group.	The London and South Western Railway Company	1,642
	The London Brighton and South Coast Railway Company	736
	The South Eastern Railway Company	637
	The London Chatham and Dover Railway Company The South Eastern and Chatham Railway Companies Managing Committee.	1,026
	Subsidiary Companies	
	The Bridgwater Railway Company	12
	The Brighton and Dyke Railway Company	8
	The Freshwater Yarmouth and Newport (Isle of Wight) Railway Company	19
	The Hayling Railways Company	8
	The Isle of Wight Railway Company	24
	The Isle of Wight Central Railway Company	46
	The Lee-on-the-Solent Railway Company	5
	The London and Greenwich Railway Company	6
	The Mid Kent Railway (Bromley to St. Mary Cray) Company	4
	The North Cornwall Railway Company	84
	The Plymouth and Dartmoor Railway Company	4
	The Plymouth, Devonport and South Western Junction Railway Company	31
	The Sidmouth Railway Company	13
	The Victoria Station and Pimlico Railway Company.	
Group	**Constituent Companies**	**Route km**
2. The Western Group.	The Great Western Railway Company	4,836
	The Barry Railway Company	109

The Cambrian Railway Company	475
The Cardiff Railway Company	19
The Rhymney Railway company	82
The Taff Vale Railway Company	200
The Alexandra (Newport and South Wales) Docks and Railway Company.	17
Subsidiary Companies	
The Brecon and Merthyr Tydfil Junction Railway Company	97
The Burry Port and Gwendreath Valley Railway Company	34
The Cleobury Mortimer and Ditton Priors Light Railway Company	19
The Didcot Newbury and Southampton Railway Company	68
The Exeter Railway Company	14
The Forest of Dean Central Railway Company	8
The Gwendreath Valleys Railway Company;	5
The Lampeter, Aberayron and New Quay Light Railway Company	19
The Liskeard and Looe Railway Company	14
The Llanelly and Mynydd Mawr Railway Company	21
The Mawddy Railway Company	
The Midland and South Western Junction Railway Company	101
The Neath and Brecon Railway Company	
The Penarth Extension Railway Company	3
The Penarth Harbour, Dock and Railway Company	16
The Port Talbot Railway and Docks Company;	56
The Princetown Railway Company;	17
The Rhondda and Swansea Bay Railway Company	46
The Ross and Monmouth Railway Company	20
The South Wales Mineral Railway Company	21
The Teign Valley Railway Company	12
The Vale of Glamorgan Railway Company	33
The Van Railway Company	

	The Welshpool and Llanfair Light Railway Campany	
	The West Somerset Railway Company	23
	The Wrexham and Ellesmere Railway Company.	
Group	**Constituent Companies**	**Route km**
3. The North Western, Midland, and West Scottish Group	The London and North Western Railway Company	4,293
	The Midland Railway Company	3,493
	The Lancashire and Yorkshire Railway Company (incl in London and North Western Railway Company)	
	The North Staffordshire Railway Company	355
	The Furness Railway Company	254
	The Caledonian Railway Company	1,794
	The Glasgow and South Western Railway Company	794
	The Highland Railway Company.	814
	Subsidiary Companies	
	The Arbroath and Forfar Railway Company	24
	The Brechin and Edzell District Railway Company	10
	The Callander and Oban Railway Company	161
	The Catheart District Railway Company	
	The Charnwood Forest Railway Company	17
	The Cleator and Workington Junction Railway Company	56
	The Cockermouth Keswick and Penrith Railway Company	49
	The Dearne Valley Railway Company	34
	The Dornoch Light Railway Company	12
	The Dundee and Newtyle Railway Company	23
	The Harborne Railway Company	4
	The Killin Railway Company	8
	The Lanarkshire and Ayrshire Railway Company	58
	The Knott End Railway Company	19
	The Leek and Manifold Valley Light Railway company;	13

Group	Constituent Companies	Route km
	The Maryport and Carlisle Railway Company;	69
	The Mold and Denbigh Junction Railway Company	24
	The North and South Western Junction Railway Company;	8
	The North London Railway Company	26
	The Portpatrick and Wigtownshire Joint Committee	132
	The Shropshire Union Railways and Canal Company	47
	The Solway Junction Railway Company	20
	The Stratford-upon-Avon and Midland Junction Railway Company	109
	The Tottenham and Forest Gate Railway Company	10
	The Wick and Lybster Light Railway Company	22
	The Wirral Railway Company	22
	The Yorkshire Dales Railway (Skipton to Grassington) Company	14
Group	**Constituent Companies**	**Route km**
4. The North Eastern, Eastern, and East Scottish Group.	The North Eastern Railway Company	2,829
	The Great Central Railway Company	1,372
	The Great Eastern Railway Company	1,917
	The Great Northern Railway Company	1,692
	The Hull and Barnsley Railway Company	171
	The North British Railway Company	2,218
	The Great North of Scotland Railway Company.	538
	Subsidiary Companies	
	The Brackenhill Light Railway Company	
	The Colne Valley and Halstead Railway Company	31
	The East and West Yorkshire Union Railways Company	15
	The East Lincolnshire Railway Company	76
	The Edinburgh and Bathgate Railway Company;	16
	The Forcett Railway Company	
	The Forth and Clyde Junction Railway Company	49
	The Gifford and Garvald Railway Company	15

The Great North of England, Clarence and Hartlepool Junction Railway Company	10
The Horncastle Railway Company	12
The Humber Commercial Railway and Dock Company	
The Kilsyth and Bonnybridge Railway Company	14
The Lauder Light Railway Company	16
The London and Blackwall Railway Company	10
The Mansfield Railway Company	16
The Mid-Suffolk Light Railway Company	31
The Newburgh and North Fife Railway Company;	21
The North Lindsey Light Railways Company	19
The Nottingham and Grantham Railway and Canal Company	37
The Nottingham Joint Station Committee	
The Nottingham Suburban Railway Company	6
The Seaforth and Sefton Junction Railway Company	
The Sheffield District Railway Company	7
The South Yorkshire Junction Railway Company	18
The Stamford and Essendine Railway Company	20
The West Riding Railway Committee.	52

C. Analysis of train weight – supporting data for Chapter 4

The following tables show the train formation used to derive the figure for each different train set shown in Figure 4.3. The data on weight and number of seats is taken from an industry reference book (Pritchard and Hall, 2013).

Mark III Electric

Table 9.3 Data for Mark III Electric trainset used for step one and Figure 4.3

Vehicle type	Weight (tonnes)	Seats
Class 87 Electric Locomotive	83.3	
Open Standard	34.3	76
Open Standard	34.3	70
Open Standard	34.3	76
Open Standard	34.3	76
Open Standard	34.3	76
Open Standard	34.3	76
Restaurant First	33.7	70
Open First	36.5	48
Open First	36.5	48
Class 87 Electric Locomotive	83.3	
TOTAL	**480.8**	**564**

Mark IV Electric – InterCity 225

Table 9.4 Data for Mark IV Electric trainset used for step one and Figure 4.3

Vehicle type	Weight (tonnes)	Seats

Class 91 Electric Locomotive	84	
Open Standard (end)	39.5	76
Open Standard	40.8	76
Open Standard	40.8	76
Open Standard	40.8	76
Open Standard (Disabled)	39.4	68
Kitchen Buffet Standard	43.2	30
Open First	41.3	41
Open First (Disabled)	40.7	42
Open First	42.1	46
Driving Brake Van (140 mph)	43.5	
TOTAL	**496.1**	**531**

Pendolino electric tilt

Class 390/0 9-car set

Table 9.5 Data for Pendolino Electric Tilt rolling stock (9-car) for step one and Figure 4.3

Vehicle type	Weight (tonnes)	Seats
DMRF (Driving Motor Restaurant First)	56.3	18
MF (Motorised First)	52.3	39
PTF (Pantograph Trailer First)	51.2	44
MF (Motorised First)	52.3	46
TS (Trailer Standard)	45.5	76
MS (Motorised Standard)	52.3	76
PTSRMB (Pantograph Trailer Standard Restaurant Manager Buffet)	53.2	48
MS (Motorised Standard)	52.5	64
DMSO (Driving Motor Standard Open)	54.5	46
TOTAL	**470.1**	**487**

Class 390/1 11-car set

Table 9.6 Data for Pendolino Electric Tilt rolling stock (11-car) for step one and Figure 4.3

Vehicle type	Weight (tonnes)	Seats
DMRF	56.3	18
MF	52.3	39
PTF	51.2	44
MF	52.3	46
TS	45.5	76
MS	52.3	76
TS	45.5	76
MS	52.3	76
PTSRMB	53.2	48
MS	52.5	64
DMSO	54.5	46
TOTAL	**567.9**	**609**

Voyager Diesel tilt

Class 221 5-car

Table 9.7 Data for Voyager Diesel Tilt rolling stock for step one and Figure 4.3

Vehicle type	Weight (tonnes)	Seats
DMSO	58.9	42
MS	54.3	68
MS	54.4	68
MSRMB	55.9	52
DMF	59.1	26
TOTAL	**282.6**	**256**

Japanese rolling stock data

This research is focused upon British rolling stock, but the following data is captured to re-create the original chart (Figure 1.5) that started this research.

Table 9.8 Data for Japanese rolling stock for step one and Figure 4.3

Shinkansen generation	Date of introduction	Weight (tonnes)	Seats
Series 0	1964	972	1,340
Series 100	1985	925	1,321
Series 300	1992	711	1,323
Series 500	1997	700	1,324
Series 700	1999	708	1,323
Series N700	2007	700	1,323
Series E5	2011	450	731

Sources:

(a) All data, except below, from UIC World High Speed Rolling Stock.
https://uic.org/IMG/pdf/20180910_highspeed_rolling_stock.pdf

(b) Seating capacity for Series 100 sourced from Wikipedia:
https://en.wikipedia.org/wiki/100_Series_Shinkansen

(c) Seating capacity for Series 0 sourced from Wikipedia:
https://en.wikipedia.org/wiki/0_Series_Shinkansen

Database of EMUs, DMUs and Bi-Mode trains used in analysis

The data given in each of the following tables is described below:

A. Class and sub-class: the identifier for the train
B. Year introduced: the year that the trainset (class or sub-class) was first introduced
C. Weight of set: the weight of the trainset
D. Seats per set: the total number of seats of the trainset (including flip seats)
E. Kg/seat: the weight of the trainset relative to the number of seats. This is the total weight of the set (C) divided by the total number of seats for the set (D).
F. Cars per set: the number of cars that make up the trainset.
G. Average weight of car: the average weight of a car for that class or sub-class. This is the total weight of the set (C) divided by the number cars that form the set (F).
H. Total sets in traffic: the total number of sets in traffic for each class and sub-class
I. Average carriage length: this is the average length of a car in a set

Table 9.9 Database of Electric Multiple Units

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 313								
313/0	1976	104.5	231	452.4	3	34.8	41	19.86
313/1	1976	105.0	231	452.4	3	35.0	3	19.86
313/2	1976	105.0	194	541.2	3	35.0	19	19.86
Class 314	1979	102.0	212	481.1	3	34.0	16	19.86
Class 315	1980	137.6	316	435.4	4	34.4	61	19.86
Class 317								
317/1	1981	137.0	292	469.2	4	34.3	12	19.88
317/5	1981	137.0	292	469.2	4	34.3	15	19.88

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
317/6	1985	137.0	258	531.0	4	34.3	24	19.88
317/7	1981	144.5	194	744.9	4	36.1	9	19.88
317/8	1981	137.0	265	517.0	4	34.3	12	19.88
Class 318	1985	116.6	205	568.8	3	38.9	21	19.88
Class 319								
319/0	1987	136.5	304	449.0	4	34.1	11	19.88
319/2	1987	142	243	584.4	4	35.5	7	19.88
319/3	1990	140.3	303	463.0	4	35.1	26	19.88
319/4	1987	138.3	267	518.0	4	34.6	39	19.88
Class 320								

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
320/3	1990	115.9	210	551.9	3	38.6	22	19.86
320/4	1990	116.2	213	545.5	3	38.7	22	19.86
Class 321								
321/3	1988	140	308	454.6	4	35.0	66	19.88
321/4	1989	140.4	299	469.6	4	35.1	40	19.88
321/9	1990	145	287	505.2	4	36.3	40	19.88
Class 322	1990	145.0	300	483.3	4	36.3	5	19.88
Class 323	1992	121.4	289	420.1	3	40.5	43	23.41
Class 331 Civity								
331/0	2017	115.5	203	569.0	3	38.5	31	23.80

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
331/1	2017	145.6	283	514.5	4	36.4	12	23.69
Class 332 - Heathrow Express	1997	221.2	241	917.8	5	44.2	14	23.44
Class 333	2001	184.5	360	512.5	4	46.1	16	23.44
Class 334 'Juniper'	1999	124.6	181	688.4	3	41.5	40	20.67
Class 345 'Crossrail' Aventra	2015	318.4	454	701.32	9	35.4	70	22.50
Class 350 'Desiro'								
350/1	2004	179.3	235	763.0	4	44.8	30	20.34
350/2	2008	166.1	276	601.8	4	41.5	37	20.34
350/3	2014	169.5	239	709.2	4	42.4	10	20.34
350/4	2013	170.0	197	862.9	4	42.5	10	20.34

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 357 'Electrostar'								
357/0	1999	157.6	282	558.9	4	39.4	46	20.43
357/2	2001	157.6	282	558.9	4	39.4	11	20.43
357/3	2001	157.6	222	709.9	4	39.4	17	20.43
Class 360 'Desiro'								
360/0	2002	167.0	281	594.3	4	41.8	21	20.34
360/2	2002	202.8	331	612.7	5	40.6	5	20.34
Class 365 'Networker Express'	1994	151.5	264	573.9	4	37.9	40	20.48
Class 373 'Eurostar'	1992	360.7	375	961.9	10	36.1	24	20.89

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 374 Siemens Velaro 'e320'	2012	455.0	448	1,015.6	8	56.9	17	25.41
Class 375 'Electrostar'								
375/3	2001	123.1	176	699.4	3	41.0	10	20.20
375/6	1999	173.6	242	717.4	4	43.4	30	20.20
375/7	2001	158.1	242	653.3	4	39.5	15	20.20
375/8	2004	162.3	242	670.7	4	40.6	30	20.20
375/9	2003	161.7	277	583.8	4	40.4	27	20.20
Class 376 'Electrostar'	2004	192.9	228	846.1	5	38.6	36	20.20
Class 377 'Electrostar'								

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
377/1	2002	162.6	234	694.9	4	40.7	64	20.20
377/2	2003	168.3	246	684.2	4	42.1	15	20.20
377/3	2001	122.4	176	695.5	3	40.8	29	20.20
377/4	2004	160.9	241	667.6	4	40.2	74	20.20
377/5	2008	168.9	241	700.8	4	42.2	23	20.20
377/6	2012	204.3	300	681.0	5	40.9	26	20.20
377/7	2013	212.3	300	707.7	5	42.5	8	20.20
Class 378 'Capitalstar'								
378/1	2009	199.6	192	1,039.6	5	39.9	20	20.30
378/2	2008	205.7	192	1,071.4	5	41.1	37	20.30

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 379 'Electrostar'	2009	163.9	211	776.8	4	41.0	30	20.20
Class 380 'Desiro'								
380/0	2009	132.6	208	637.5	3	44.2	22	23.00
380/1	2009	167.4	282	593.6	4	41.9	16	23.00
Class 387								
387/1 – Great Northern	2014	174.8	225	776.9	4	43.7	29	20.39
387/1 - Great Western Railway units	2014	174.8	225	776.9	4	43.7	45	20.39
387/2	2014	174.8	223	783.9	4	43.7	27	20.39
387/3	2014	174.8	225	776.9	4	43.7	6	20.39

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 390 'Pendolino'								
390/0	2001	470.1	487	965.3	9	52.2	21	24.35
390/1	2001	567.9	609	932.5	11	51.6	35	24.35
Class 395 'Javelin'	2006	276.2	352	784.7	6	46.0	29	20.44
Class 442	1988	206.1	346	595.66	5	41.2	24	23.08
Class 444 'Desiro'	2003	221.5	361	613.57	5	44.3	45	23.57
Class 445	1971	140.0	280	500.0	4	35.0	2	19.87
Class 446	1972	70.0	136	514.7	2	35.0	1	19.80
Class 450 'Desiro'								
450/0	2002	172.2	270	637.8	4	43.1	99	20.40

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
450/5	2002	171.9	251	684.9	4	43.0	28	20.40
Class 455								
455/7	1984	133.4	244	546.7	4	33.4	43	19.88
455/8 - Southern Units	1982	146.8	310	473.5	4	36.7	46	19.88
455/8 - South Western Railway Units	1982	131.7	244	539.8	4	32.9	28	19.88
455/9	1982	131.7	244	539.8	4	32.9	20	19.88
Class 456	1990	75.6	118	640.7	2	37.8	24	19.83
Class 458 'Juniper'	1998	199.2	274	727.0	5	39.8	36	20.55
Class 465 'Networker'								

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
465/0	1991	133.6	348	383.9	4	33.4	50	20.48
465/1	1993	133.6	348	383.9	4	33.4	47	20.48
465/2	1991	135.8	348	390.2	4	34.0	16	20.48
465/9	1991	138.2	322	429.2	4	34.6	34	20.48
Class 466 'Networker'	1993	72.0	168	428.6	2	36.0	43	20.89
Class 483	1989	54.8	82	668.3	2	27.4	6	16.15
Class 507	1978	98.0	192	510.4	3	32.7	32	19.86
Class 508	1979	99.0	192	515.6	3	33.0	27	19.86
Class 700 'Desiro City'								
700/0 - 8-car units	2014	273.5	433	631.6	8	34.2	60	20.40

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
700/1 - 12-car units	2013	399.6	672	594.6	12	33.3	55	20.40
Class 707 'Desiro City'	2015	160.3	275	582.9	5	32.1	30	20.08
Class 710 'Aventra'								
710/2 4-car units	2017	157.8	189	834.9	4	39.5	18	20.72
Class 717 'Desiro City'	2017	204.5	377	542.4	6	34.1	25	20.00
Class 801 InterCity Express Programme Electric								
801/1 5-car LNER units	2016	238.7	302	790.4	5	47.7	12	25.14

Table 9.10 Database of Diesel Multiple Units

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 121	1960	38.0	65	584.6	1	38.0	1	20.45
Class 139	2007	12.5	21	595.2	1	12.5	2	8.70
Class 142 'Pacer'	1985	49.5	111	445.9	2	24.8	94	15.55
Class 143 'Pacer'	1985	49.5	104	476.0	2	24.8	23	15.55
Class 144 'Pacer'								
144: 3-car	1986	48.5	92	527.2	2	24.3	10	15.29
144: 2-car	1986	72.0	150	480.0	3	24.0	3	15.29
Class 150 'Sprinter'								
150/0	1984	105.1	239	439.7	3	35.0	2	20.10

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
150/1	1985	76.4	147	519.7	2	38.2	50	20.12
150/2	1986	72.3	122	592.6	2	36.2	84	20.12
Class 153 'Super Sprinter'	1987	41.2	72	572.2	1	41.2	70	23.29
Class 155 'Super Sprinter'	1988	79.4	140	567.1	2	39.7	7	23.29
Class 156 'Super Sprinter'	1988	74.7	150	498.0	2	37.4	114	23.03
Class 158 'Express'								
158/0 2-car	1989	77.0	138	558.0	2	38.5	126	23.20
158/0 3-car	1989	115.5	206	560.7	3	38.5	9	23.20
158/8	1989	77.0	125	616.0	2	38.5	11	23.20
158/9	1989	77.0	142	542.3	2	38.5	10	23.20

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
158/0 - Great Western	1989	115.5	208	555.3	3	38.5	10	23.20
Class 159								
159/0	1992	115.5	199	580.4	3	38.5	22	23.20
159/1	1989	115.5	192	601.6	3	38.5	8	23.20
Class 165 'Network Turbo'								
165/0 2-car	1992	83.6	178	469.7	2	41.8	28	22.85
165/0 3-car	1992	120.6	284	424.7	3	40.2	11	22.85
165/1 2-car	1992	77.8	157	495.5	2	38.9	20	22.85
165/1 3-car	1992	115.9	263	440.7	3	38.6	16	22.85

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 166 'Networker Express Turbo'	1992	120.7	244	494.7	3	40.2	21	22.82
Class 168 'Clubman'								
168/0	1997	169.6	275	616.7	4	42.4	5	23.62
168/1 4-car	2000	175.1	275	636.7	4	43.8	2	23.62
168/1 3-car	2000	132.2	202	654.5	3	44.1	6	23.62
168/2	2000	177.5	278	638.5	4	44.4	6	23.62
168/3	2000	91.6	128	715.6	2	45.8	9	23.62
Class 170 'Turbostar'								
170/1 3-car	1998	132.8	200	664.0	3	44.3	10	23.62

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
170/1 2-car	1998	89.8	120	748.3	2	44.9	7	23.62
170/2 3-car Greater Anglia	1999	131.9	186	709.1	3	44.0	8	23.62
170/2 2-car Greater Anglia	2002	91.4	119	768.1	2	45.7	4	23.62
170/3 ex-Hull Trains units	2004	138.2	193	716.1	3	46.1	4	23.62
170/3 Cross Country units	2002	134.2	200	671.0	3	44.7	2	23.62
170/4 ScotRail "express" (1)	1999	132.9	186	714.5	3	44.3	20	23.62
170/4 ScotRail "express" (2)	2003	137	186	736.6	3	45.7	10	23.62
170/4 ScotRail & Northern	2004	136.1	198	687.4	3	45.4	12	23.62
170/4 standard only	2001	132.6	198	669.7	3	44.2	8	23.62
170/5	1999	91.7	122	751.6	2	45.9	23	23.62

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
170/6	2000	134.1	196	684.2	3	44.7	9	23.62
Class 171 'Turbostar'								
171/7	1999	95.4	116	822.4	2	47.7	10	23.62
171/8	2004	180.4	259	696.5	4	45.1	6	23.62
Class 172 'Turbostar'								
172/0	2009	83.1	137	606.6	2	41.6	8	23.27
172/1	2009	84.2	145	580.7	2	42.1	4	23.27
172/2	2010	84.4	139	607.2	2	42.2	12	23.27
172/3	2010	123.2	219	562.6	3	41.1	15	23.30
Class 175 'Coradia 1000'								

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
175/0	1999	99.5	118	843.2	2	49.8	11	23.03
175/1	1999	147.7	186	794.1	3	49.2	16	23.01
Class 180	2000	252.5	268	942.2	5	50.5	14	23.37
Class 185 'Desiro'	2005	163.0	181	900.6	3	54.3	51	23.76
Class 220 'Voyager'	2000	194.6	200	973.0	4	48.7	34	23.62
Class 221 'Super Voyager'	2001	280.7	262	1,071.4	5	56.1	44	23.67
Class 222 ' Meridian'								
Class 222 7-car units	2004	337.8	342	987.7	7	48.3	7	23.43
Class 222 5-car units	2003	249	242	1,028.9	5	49.8	17	23.43
Class 222 4-car units	2005	197.3	181	1,090.1	4	49.3	4	23.43

Table 9.11 Database of Bi-Mode Multiple Units

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 755 'Flirt Bi-mode'								
755/3 - 3-car units	2018	138.5	167	829.3	3	46.2	14	20.81
755/4 - 4-car units	2018	163.5	229	714.0	4	40.9	24	20.81
Class 800 InterCity Express Programme Bi-Mode								
800/0 5-car Great Western Units	2013	250.5	326	768.4	5	50.1	36	25.23
800/1 Azuma Bi-mode 9-car LNER Units	2013	429.5	611	703.0	9	47.7	13	25.23
800/2 Azuma Bi-mode 5-car LNER Units	2018	250.5	302	829.5	5	50.1	10	25.23
800/3 9-car Great Western Units	2017	429.2	647	663.4	9	47.7	21	25.23

Class and Sub-Class	Year introduced	Weight of set	Seats per set	kg/seat	Cars per set	Average weight of car	Total sets in traffic	Average carriage length
Class 802 AT300								
802/0 5-car Great Western Units	2017	252.8	326	775.5	5	50.6	22	25.18
802/1 Bi-mode 9-car Great Western units	2017	430.3	647	665.1	9	47.8	14	25.18
802/2 Bi-mode 5-car TPE units	2019	251.5	340	739.7	5	50.3	5	25.18

This table shows the classes of EMUs split by tranche that are used for the analysis in section 4.4, page 92.

Table 9.12 Classes of Electric Multiple Units included within each tranche for the analysis in step three

Tranche 1	445, 446, 313/0, 313/1, 313/2, 314, 315, 317/1, 317/5, 317/6, 317/7, 317/8, 318, 319/0, 319/2, 319/3, 319/4, 320/3, 320/4, 321/3, 321/4, 321/9, 322, 507, 508
Tranche 2	365, 465/0, 465/1, 465/2, 465/9, 466
Tranche 3	334, 350/1, 350/2, 350/3, 350/4, 357/0, 357/2, 357/3, 360/0, 360/2, 375/3, 375/6, 375/7, 375/8, 375/9, 376, 377/1, 377/2, 377/3, 377/4, 377/5, 377/6, 377/7, 378/1, 378/2, 379, 387/1 (Northern), 387/1 (Great Western), 387/2, 387/3, 450/0, 450/5, 458
Tranche 4	345 'Crossrail' Aventra, 700/0 Thameslink 8-car, 700/1 Thameslink 12-car, Class 707

D. Analysis of recent decisions – supporting data

Freedom of Information Request – Thameslink

The following email was sent as a Freedom of Information request on Tuesday 28 March 2017 to *contact@thameslinkprogramme.co.uk*

> *Dear Sir or Madam*
>
> *For my research I would like to see a copy of the Pre-Qualification Questionnaire that was used in the tender process for the procurement of the thameslink rolling stock and associated services.*
>
> *I believe the Pre-Qualification OJEU was issued in April 2008*
>
> *I would like also like a copy of the Invitation to Tender which was subsequently issues in November 2008.*
>
> *These documents were part of the competitive tender process.*
>
> *Yours faithfully,*
>
> *Michael King*

The following reply was received via email as a pdf attachment on 24 April 2017 and is copied below.

> *Dear Mr King,*
>
> ***Freedom of Information Act Request – F0014719***
>
> *Thank you for your request for information which we received on 30 March 2017. You requested:*
>
> ***For my research I would like to see a copy of the Pre-Qualification Questionnaire that was used in the tender process for the procurement of the Thameslink rolling stock and associated services. I believe the Pre-Qualification OJEU was issued in April 2008 I would like also like a copy of***

the Invitation to Tender which was subsequently issued in November 2008. These documents were part of the competitive tender process.

Your request for information has been considered under the Freedom of Information (FOI) Act 2000. I am writing to confirm that the Department for Transport (DfT) has now completed its search for the information and that we hold information that is relevant to your request.

During the Thameslink rolling stock procurement competition, an OJEU Notice was published in April 2008. At OJEU stage, bidders were asked to complete an Accreditation Questionnaire in order to qualify to receive an Invitation to Tender (ITT) in the next stage of the procurement competition. A Pre-Qualification Questionnaire was not completed as the Accredited Questionnaire was used to provide a thorough evaluation and accreditation of applicants.

Under section 21 of the Act (the full text of the exemption is attached at Annex A) we are not required to provide information which is already reasonably accessible to you.

The Thameslink Rolling Stock project Accreditation Questionnaire, OJEU and ITT documents can be found via the link below:
https://www.gov.uk/government/publications/thameslink-rolling-stock-project--14

…

Please see attached details of DfT's complaints procedure and your right to complain to the Information Commissioner.

Yours sincerely,

Mr Craig Welsh

Correspondence Manager – Passenger Services

Thameslink OJEU Notice (Official Journal of the European Union)

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1.0/026341
TI: UK-London: passenger transport by railway
PD: 20080411
ND: 96012-2008
OJ: 71/2008
DR: 20080409
DS: 20080409
DT: 20080609  12 00
HD: 2540
TD: 3 - Contract notice
NC: 2 - Supply contract
PR: 4 - Negotiated procedure
RP: 4 - European Communities
AA: 4 - Utilities
TY: 1 - Global tender
AC: 2 - The most economic tender
MA: R - Railway services
PC: 35220000
    45234100
    45234112
    50222000
    60111000
    60112000
    66000000
    66200000
PN: Rolling stock
    Railway construction works
    Railway depot
    Repair and maintenance services of rolling stock
    Passenger transport by railway
    Public transport services
    Financial intermediation services
    Investment banking services
CY: UK
OL: EN
AU: DEPARTMENT FOR TRANSPORT
TW: LONDON
IA: www.dft.gov.uk
AB: Title attributed to the contract by the contracting entity: UK-
London: thameslink rolling stock.
    The Department is initiating the process of procuring train provision
and associated services for, and on behalf of the train operating company
operating the Thameslink/GN franchise (the 'TOC') and the advertised
contract is likely to be entered into by the TOC.
    The procurement uses the negotiated procedure to select a party which
will supply and maintain the fleet of new rolling stock. The Department
intends that the chosen bidder will be required to arrange the finance
necessary for the acquisition and ownership of the rolling stock. The ITT
would therefore require bidders to submit bids covering the supply and
maintainance of the new rolling stock, together with arranging the
necessary finance.
    However, interested parties should be aware that the Department
reserves the right to decide not to require the chosen bidder to arrange
finance, in which case the ITT may require bids for supplying and
maintaining the new rolling stock without the need to arrange finance.
    In either case, the Department may seek to include in this
procurement the development of one or more train depots.
    Further details will be provided in the ITT documentation.
```

The contract or contracts necessary to give effect to this are referred to in this notice as "the contract".

It is anticipated that the contract will be awarded mid 2009.

Expressions of interest are invited from organisations that can demonstrate they:

A. Have the technical capability and financial standing to supply, and manage, the complete package of rolling stock; long term maintenance and depots (maintenance and servicing facilities).

B. Capability to arrange the finance necessary for the acquisition and ownership of the rolling stock.

C. Possess the necessary production, supply chain, project management skills and resources and technical expertise required to design and manufacture dual-voltage passenger carrying trains which deliver:

c1. A safe, consistently reliable journey.

c2. An environmentally sustainable solution.

c3. Customer expectations on ambiance, amenities and facilities,

c4. Whole life/whole system value for money, and, compared to the existing Thameslink fleet:

c5. Increased capacity per train.

c6. Increased capacity on the network, plus.

c7. Improved safety and security.

D. Can demonstrate the capability to specify the servicing and maintenance regime necessary to optimize the availability and reliability during the life of the vehicles.

E. Can specify, design, build and operate appropriate new, or refurbish existing, depot and servicing facilities for their recommended servicing and maintenance regime within the constraints of the network; the timetables, routes and diagrams operated by the TOC; and other operational demands.

F. Can maintain and service the vehicles over the life of the vehicles.

G. Will obtain train acceptance and full operational approval (working in conjunction with Network Rail, the TOC and other relevant parties) onto the selected routes.

H. Remain the design authority for the life of the vehicles.

Important notes:

1. The Department has not yet adopted a final view on whether the provision of depots will be included in the contract and reserves the right to conduct a separate competition for this element of the procurement.

2. Consistent with HM Treasury guidance on best practice, the Department reserves the right to run a funding competition.

3. The Department intends soon after issue of this notice to hold an industry briefing day. Advance information regarding this event (including the date and time) will be provided on registering at trsp@dft.gsi.gov.uk.

CPV: 60111000, 50222000, 60112000, 66000000, 35220000, 45234100, 45234112, 66200000.

TX: CONTRACT NOTICE - UTILITIES

Supplies

SECTION I: CONTRACTING ENTITY

I.1) NAME, ADDRESSES AND CONTACT POINT(S): Department for Transport, Floor 3, Great Minster House, 76 Marsham Street, Attn: Eddie Muraszko, UK-London SW1P 4DR. Tel. (44) 20 79 44 34 20. E-mail: trsp@dft.gsi.gov.uk.

Fax (44) 20 79 44 21 77.

Internet address(es):

General address of the contracting entity: www.dft.gov.uk.

Further information can be obtained at: As in above-mentioned contact point(s).

Specifications and additional documents (including documents for a dynamic purchasing system) can be obtained at: As in above-mentioned contact point(s).

Tenders or requests to participate must be sent to: As in above-mentioned contact point(s).

I.2) MAIN ACTIVITY OR ACTIVITIES OF THE CONTRACTING ENTITY: Railway services.

SECTION II: OBJECT OF THE CONTRACT

II.1) DESCRIPTION

II.1.1) Title attributed to the contract by the contracting entity: UK-London: thameslink rolling stock.

II.1.2) Type of contract and location of works, place of delivery or of performance: Supplies.

A combination of purchase, lease, rental and hire purchase.

Main place of delivery: England.

Nuts Code: UK.

II.1.3) The notice involves: A public contract.

II.1.5) Short description of the contract or purchase(s): The Department is initiating the process of procuring train provision and associated services for, and on behalf of the train operating company operating the Thameslink/GN franchise (the 'TOC') and the advertised contract is likely to be entered into by the TOC.

The procurement uses the negotiated procedure to select a party which will supply and maintain the fleet of new rolling stock. The Department intends that the chosen bidder will be required to arrange the finance necessary for the acquisition and ownership of the rolling stock. The ITT would therefore require bidders to submit bids covering the supply and maintainance of the new rolling stock, together with arranging the necessary finance.

However, interested parties should be aware that the Department reserves the right to decide not to require the chosen bidder to arrange finance, in which case the ITT may require bids for supplying and maintaining the new rolling stock without the need to arrange finance.

In either case, the Department may seek to include in this procurement the development of one or more train depots.

Further details will be provided in the ITT documentation.

The contract or contracts necessary to give effect to this are referred to in this notice as "the contract".

It is anticipated that the contract will be awarded mid 2009.

Expressions of interest are invited from organisations that can demonstrate they:

A. Have the technical capability and financial standing to supply, and manage, the complete package of rolling stock; long term maintenance and depots (maintenance and servicing facilities).

B. Capability to arrange the finance necessary for the acquisition and ownership of the rolling stock.

C. Possess the necessary production, supply chain, project management skills and resources and technical expertise required to design and manufacture dual-voltage passenger carrying trains which deliver:

c1. A safe, consistently reliable journey.

c2. An environmentally sustainable solution.

c3. Customer expectations on ambiance, amenities and facilities,

c4. Whole life/whole system value for money, and, compared to the existing Thameslink fleet:

c5. Increased capacity per train.

c6. Increased capacity on the network, plus.
c7. Improved safety and security.
D. Can demonstrate the capability to specify the servicing and maintenance regime necessary to optimize the availability and reliability during the life of the vehicles.
E. Can specify, design, build and operate appropriate new, or refurbish existing, depot and servicing facilities for their recommended servicing and maintenance regime within the constraints of the network; the timetables, routes and diagrams operated by the TOC; and other operational demands.
F. Can maintain and service the vehicles over the life of the vehicles.
G. Will obtain train acceptance and full operational approval (working in conjunction with Network Rail, the TOC and other relevant parties) onto the selected routes.
H. Remain the design authority for the life of the vehicles.
Important notes:
1. The Department has not yet adopted a final view on whether the provision of depots will be included in the contract and reserves the right to conduct a separate competition for this element of the procurement.
2. Consistent with HM Treasury guidance on best practice, the Department reserves the right to run a funding competition.
3. The Department intends soon after issue of this notice to hold an industry briefing day. Advance information regarding this event (including the date and time) will be provided on registering at trsp@dft.gsi.gov.uk.
II.1.6) Common procurement vocabulary (CPV): 60111000, 50222000, 60112000, 66000000, 35220000, 45234100, 45234112, 66200000.
II.1.7) Contract covered by the Government Procurement Agreement (GPA):
No.
II.1.8) Division into lots: Yes.
Tenders should be submitted for: all lots.
II.1.9) Variants will be accepted: Yes.
II.2) QUANTITY OR SCOPE OF THE CONTRACT
II.2.1) Total quantity or scope: Supply between 900 and 1300 new vehicles. Introduction of the new vehicles into passenger service is expected to start in February 2012 and all the new vehicles are expected to be in passenger service by December 2015. The successful bidder will be responsible for maintaining the trains over a period to be determined, which is currently expected to be approximately 7 to 10 years.
II.2.2) Options: Yes.
Description of these options: Information will be provided with the Invitation to Tender (ITT).
in the case of renewable contracts, estimated time-frame for subsequent calls for competition: in months: 160 (from the award of the contract).
II.3) DURATION OF THE CONTRACT OR TIME LIMIT FOR COMPLETION:
Duration in months: 160 (from the award of the contract).
INFORMATION ABOUT LOTS
LOT NO 1
TITLE UK-London: supply and maintain rolling stock and, if appropriate, arrange the finance necessary for the acquisition and ownership of the rolling stock

1) SHORT DESCRIPTION: Supply and maintain the fleet of new rolling stock and, if appropriate, arrange the finance necessary for the acquisition and ownership of the rolling stock.

2) COMMON PROCUREMENT VOCABULARY (CPV): 60111000, 45234100, 66200000, 60112000, 66000000, 35220000, 50222000.

3) QUANTITY OR SCOPE: Supply between 900 and 1300 new vehicles. Introduction of the new vehicles into passenger service is expected to start in February 2012 and all the new vehicles are expected to be in passenger service by December 2015. The successful bidder will be responsible for maintaining the trains over a period to be determined, which is currently expected to be approximately 7 to 10 years.

LOT NO 2

TITLE UK-London: train depot(s) and, if appropriate, arrange the necessary related finance

1) SHORT DESCRIPTION: Procure one or more train depots for the Thameslink rolling stock and, if appropriate, arrange the necessary related finance.

The depot(s) must be operational to support the introduction and ongoing service and operation of the rolling stock.

2) COMMON PROCUREMENT VOCABULARY (CPV): 45234112.

4) INDICATION ABOUT DIFFERENT DATE FOR DURATION OF CONTRACTOR STARTING/COMPLETION: Duration in months: 72 (from the award of the contract).

SECTION III: LEGAL, ECONOMIC, FINANCIAL AND TECHNICAL INFORMATION

III.1) CONDITIONS RELATING TO THE CONTRACT

III.1.1) Deposits and guarantees required: Information will be provided in the ITT.

III.1.2) Main financing conditions and payment arrangements and/or reference to the relevant provisions regulating them: Information will be provided in the ITT.

III.1.3) Legal form to be taken by the grouping of economic operators to whom the contract is to be awarded: Information will be provided in the ITT.

III.1.4) Other particular conditions to which the performance of the contract is subject: No.

III.2) CONDITIONS FOR PARTICIPATION

III.2.1) Personal situation of economic operators, including requirements relating to enrolment on professional or trade registers: Information and formalities necessary for evaluating if requirements are met: Interested parties are asked to submit an expression of interest by returning the AQ available from the Department's website [http://www.dft.gov.uk/pgr/rail/pi/trsp].

Consortia formed (or capable of being formed) by interested parties for the purposes of the procurement should submit a joint AQ.

III.2.2) Economic and financial capacity: Detailed in the AQ.

III.2.3) Technical capacity: Information and formalities necessary for evaluating if requirements are met: Detailed in the AQ.

III.2.4) Reserved contracts: No.

III.3) CONDITIONS SPECIFIC TO SERVICES CONTRACTS

III.3.1) Execution of the service is reservedto a particular profession: No.

SECTION IV: PROCEDURE

IV.1) TYPE OF PROCEDURE

IV.1.1) Type of procedure: Negotiated

Candidates have already been selected: no.

IV.2) AWARD CRITERIA

IV.2.1) Award criteria: The most economically advantageous tender in terms of the criteria stated in the specifications or in the invitation to tender or to negotiate.
IV.2.2) An electronic auction will be used: No.
IV.3) ADMINISTRATIVE INFORMATION
IV.3.2) Previous publication concerning the same contract: No.
IV.3.3) Conditions for obtaining specifications and additional documents: Payable documents: no.
IV.3.4) Time limit for receipt of tenders or requests to participate: 9.6.2008 - 12:00.
IV.3.5) Language(s) in which tenders or requests to participate may be drawn up: English.
IV.3.7) Conditions for opening tenders: Persons authorised to be present at the opening of tenders: no.
SECTION VI: COMPLEMENTARY INFORMATION
VI.1) THIS IS A RECURRENT PROCUREMENT: No.
VI.2) CONTRACT(S) RELATED TO A PROJECT AND/OR PROGRAMME FINANCED BY COMMUNITY FUNDS: No.
VI.3) ADDITIONAL INFORMATION: GO reference: GO 08040904/01.
VI.5) DATE OF DISPATCH OF THIS NOTICE: 9.4.2008.

Thameslink TTS and TIIS evaluation criteria (Appendix K of the ITT)

Appendix K

TTS and TIIS evaluation criteria

1. TENDER EVALUATION STAGE 1 - MANDATORY TECHNICAL REQUIREMENTS

The following requirements of the Train Technical Specification (TTS) and Train – Infrastructure Interface Specification (TIIS) are considered critical and will be evaluated in Stage 1 of the Evaluation Process (reference section 3.1.1 of the ITT).

Guidance is given on the evidence which is expected to be submitted by the Bidder in support of a compliant response. The evidence supplied must enable the Department to ascertain whether the proposed design will comply with the critical requirements. It is in the interest of the Bidder to ensure that the critical requirements are addressed in an unambiguous way which does not require any subjective assessment or professional judgment.

Table K1 TTS mandatory criteria

TTS		
Clause	Title	Compliance to be shown by:
5.1.3-5	Unit Configuration	Reference to the Unit Concept Design showing how the requirements will be met
5.2.1	Unit Capacity	Reference to the Unit Concept Design and modelling submission under Clause 6.6
5.4	Floor Height	Reference to the Unit Concept Design showing how the requirements will be met
5.6	Multiple Unit Operation	Reference to the Unit Concept Design showing how the requirements will be met
5.7	Coupling	Reference to the Unit Concept Design showing the proposed coupler arrangements and systems
5.9	Automatic Train Operation	Reference to the Unit Concept Design showing the proposed train control system
6.1	Running Times	Performance analysis
6.2	Traction and Braking Performance	Performance analysis
6.3	Traction Supply	Reference to the Unit Concept Design showing how the requirements will be met
6.4	Operational Routes	Confirmation that the Units will be capable of operating on all routes specified in the TIIS plus relevant sidings and depots
6.6	Dwell Time	Legion modelling supported by descriptions of the proposed door system and response times.
7.1	General	RAMS analysis compliant with the requirements

	Reliability	of EN50126-1:1999 (or equivalent) continuing through the entire project life and referenced to the train architecture defined the Unit Concept Design
9.11.3	PRM Requirements	Reference to the Unit Concept Design showing how the requirements will be met
10.1	Power Supply Changeover	Reference to the Unit Concept Design showing how the requirements will be met.
10.2.1	Regenerative Braking	Reference to the Unit Concept Design showing how the requirements will be met.
10.3.2	Auxiliary Power Supply	Reference to the Unit Concept Design showing how the requirements will be met. Preliminary battery capacity and power consumption calculations showing how the requirement will be met.
10.4.5 & 6	Braking System	Reference to the Unit Concept Design showing how the requirements will be met and setting out the capabilities of the parking brake and "hill start" facilities.
10.7.1 & 2	Door Systems	Reference to the Unit Concept Design showing that the required modes of operation will be accommodated
10.8	Selective Door Operation	Reference to the Unit Concept Design showing that the required modes of operation will be accommodated
11.1	Signalling and Control	Reference to the Unit Concept Design supported by evidence of the selection and description of suitable signalling and control systems

Table K2 TIIS mandatory criteria

TIIS		
Clause	Title	Compliance to be shown by:
2.1 TIIS_1584	Gauge	Provision of a demonstration be the derivation of a Kinematic Envelope as specified in TIIS_1591
2.1.2.2 TIIS_1555	Platform Length	Provision of vehicle general layout drawings illustrating door positions and key dimensions.
2.2.1 all except TIIS_1759	Contact patch energy	Provision of Tγ curves produced in accordance with the assumptions listed.
2.3 TIIS_1831	Structures	Provision of vehicle diagrams as specified in Appendix F of GM/RT2149.
2.3 TIIS_1939	Structures	Provision of a compliant RA rating in accordance with GE/RT8006
2.4 TIIS_234	Energy	Description of the proposed unit, supported by evidence of the selection and description of a suitable traction package.

2.4.1.4 TIIS/1785, 1841, 1751 & 1765	OLE/ Pantograph	Provision of gauging portfolio illustrating pantograph positions and key dimensions. Provision of pantograph drawings showing the working range and other key features.
2.4.2.4 TIIS_1766	Current Collector Performance	Provision of gauging portfolio illustrating shoegear positions and key dimensions.
2.4.3.3 TIIS_1721	Automatic Changeover	Description of the proposed automatic changeover system demonstrating its suitability for purpose.
2.5 All	Train Control Systems	Description of the proposed control, protection and warning equipment, demonstrating its suitability for purpose.
2.5.1 All	Signalling	Description of the proposed ETCS equipment demonstrating its suitability for purpose.
2.5.2 TIIS_1626 & 1746	Driver-Signaller Communication	Description of the proposed GSM-R cab radio and data radio equipment demonstrating their suitability for purpose.
2.5.3.2 All	Braking	Provision of preliminary brake performance calculations.
2.5.5 TIIS_326	Automatic Warning System	Description of the proposed AWS equipment demonstrating its suitability for purpose.
2.5.7 TIIS_1194	Automatic Train Operation	Description of the proposed ATO equipment demonstrating its suitability for purpose.
2.5.7.1 TIIS_1894	Stopping Accuracy	Description of the proposed ATO equipment demonstrating its suitability for purpose.
2.5.7.2 All	Emergency Cut Out	Description of the proposed ATO equipment demonstrating its suitability for purpose.
2.5.7.6 TIIS_1679	Station Stops	Description of the proposed ATO equipment demonstrating its suitability for purpose.
2.5.8 All	European Train Control System	Description of the proposed ETCS equipment demonstrating its suitability for purpose.
2.5.10 TIIS_1493	GSM-R Radio	Description of the proposed GSM-R equipment demonstrating its suitability for purpose.
2.5.11 TIIS_358	Automatic Selective Door Opening	Description of the proposed ASDO equipment demonstrating its suitability for purpose.

2. TENDER EVALUATION STAGE 2 – COMPATIBILITY WITH TTS AND TIIS

Compliance with those elements of the TTS and TIIS not considered mandatory in the Stage 1 evaluation are evaluated in Stage 2. The evaluation will take the form of a score out of 100 for each of the TTS and TIIS as set out in the tables K3 and K4 below.

Table K3 TTS scoring matrix

Clause	Description	Comments	Percentage of section attributed to scored aspects	Section Totals
1	**IMPORTANT NOTICE**			**0%**
2	**INTRODUCTION**			**0%**
3	**ABBREVIATIONS AND DEFINITIONS**			**0%**
4	**STANDARDS, APPROVAL AND ENVIRONMENT**			**3%**
4.1	STANDARDS AND LEGISLATION	Standards and Legislation	0%	
4.2	OPERATING ENVIRONMENT	Scored	100%	
5	**UNIT REQUIREMENTS**			**16%**
5.1	UNIT CONFIGURATION.	Scored except 5.1.3 - 5.1.5 which are Stage 1	10%	
5.2	UNIT CAPACITY	Scored except 5.2.1 which is Stage 1	50%	
5.3	UNIT MASS	Scored	12%	
5.4	FLOOR HEIGHT	Scored except 5.4.1 which is Stage 1	5%	
5.5	INTER CAR GANGWAYS	Scored	10%	
5.6	MULTIPLE UNIT OPERATION	Stage 1 except 5.6.6 and 5.6.7 which are scored	5%	
5.7	COUPLING	Stage 1	0%	
5.8	EMERGENCY RESCUE	Scored	8%	
5.9	AUTOMATIC TRAIN OPERATION	Stage 1	0%	
6	**PERFORMANCE CAPABILITIES**			**6%**
6.1	RUNNING TIMES	Stage 1 except 6.1.12 which is scored	30%	
6.2	TRACTION AND BRAKING PERFORMANCE	Stage 1 except 6.2.5 and 6.2.6 which are scored	5%	
6.3	TRACTION SUPPLY	Stage 1	0%	
6.4	OPERATIONAL ROUTES	6.4.1 Stage 1 6.4.2 Scored	20%	
6.5	OPERATIONAL CONFIGURATION TIMES	Scored	30%	
6.6	STATION DWELL TIME	Stage 1 except 6.6.4 which is scored	12%	
6.7	CAPACITIES BETWEEN SERVICING	Scored	3%	
7	**RELIABILITY**			**30%**
7.1	GENERAL	Scored except 7.1.3 which is Stage 1	0%	
7.2	MEAN DISTANCE BETWEEN SERVICE AFFECTING FAILURES	Scored	40%	
7.3	MISSION FAILURES	Scored	34%	
7.4	TECHNICAL DELAYS	Scored	13%	
7.5	DESIGN FOR RELIABILITY	Scored	13%	
8	**TRAIN WIDE FUNCTIONS**			**13%**

8.1	GAUGE AND TRACK INTERACTION	8.1.1 marked in TIIS 8.1.2 scored. 8.1.3 - 5 are standards related.	8%	
8.2	WHEEL RAIL INTERFACE	marked in TIIS	0%	
8.3	ENERGY USAGE AND EFFICIENCY	Scored except 8.3.12 which is Standards.	8%	
8.4	RIDE QUALITY	Scored	3%	
8.5	AERODYNAMICS AND PRESSURE EFFECTS	Scored except 8.5.2 which is standards related	3%	
8.6	NOISE AND VIBRATION	Scored	3%	
8.7	FIRE SAFETY	Scored except 8.7.2 and 8.7.4 which are standards related	16%	
8.8	HUMAN FACTORS AND ERGONOMICS.	Scored	8%	
8.9	SECURITY, ANTI SOCIAL BEHAVIOUR AND VANDALISM RESISTANCE.	Scored	8%	
8.10	FLEXIBILITY.	Scored	40%	
8.11	RECYCLABILITY	Scored	3%	
9	**GENERAL VEHICLE DESIGN**			**15%**
9.1	VEHICLE DESIGN	Scored	3%	
9.2	EXTERIOR REQUIREMENTS	Scored except 9.2.8 which is standards related	13%	
9.3	INTERIOR DESIGN	Scored	13%	
9.4	SEATING PROVISION	Scored	13%	
9.5	TOILETS	Scored	13%	
9.6	LUGGAGE AND CYCLE STOWAGE	Scored	13%	
9.7	SIGNAGE	Scored	3%	
9.8	CATERING	Scored	3%	
9.9	LITTER	Scored	3%	
9.10	CLEANABILITY	Scored	3%	
9.11	PRM REQUIREMENTS	Scored except 9.11.3 which is Stage 1	13%	
9.12	CAB DESIGN	Scored except 9.12.2 which is standards related	7%	
10	**SYSTEM FUNCTIONS**			**15%**
10.1	POWER SUPPLY CHANGEOVER.	Stage 1	0%	
10.2	REGENERATIVE BRAKING	10.2.1 Stage 1 10.2.2 Scored	3%	
10.3	AUXILIARY POWER SUPPLY	10.3.1 Scored 10.3.2 Stage 1	3%	
10.4	BRAKING SYSTEM	Scored except 10.4.5 & 6 which are Stage 1	3%	
10.5	WHEEL SLIP AND SLIDE CONTROL	Scored	3%	
10.6	VIGILANCE SYSTEM.	Standards	0%	
10.7	DOOR SYSTEMS	Scored except 10.7.1 - 2 which are Stage 1	6%	
10.8	SELECTIVE DOOR OPERATION	Stage 1	0%	
10.9	HEATING VENTILATION AND COOLING	Scored	6%	
10.10	WARNING HORNS	Standards	0%	
10.11	EXTERIOR LIGHTS	Standards	0%	
10.12	INTERIOR LIGHTING	Scored	6%	

10.13	PASSENGER INFORMATION AND COMMUNICATIONS	Scored	14%	
10.14	STORAGE OF INVESTIGATIVE DATA	Scored except 10.14.1 which is standards related	3%	
10.15	TRAIN MANAGEMENT SYSTEM	Scored	13%	
10.16	PASSENGER COUNTING SYSTEM	Scored	3%	
10.17	FORWARD FACING CCTV	Scored	3%	
10.18	DRIVER ONLY OPERATION CCTV	Scored	13%	
10.19	INTERNAL SALOON CCTV	Scored	3%	
10.20	FIRE DETECTION SYSTEM	Scored	13%	
10.21	INFRASTRUCTURE MONITORING SYSTEM	TIIS	1%	
10.22	TRACTION CONTROL	Scored	3%	
10.23	WINDSCREEN WIPER SYSTEM	Scored	1%	
11	**SIGNALLING AND TRAIN COMMUNICATIONS.**			**1%**
11.1	SIGNALLING AND CONTROL.	Stage 1 except : 11.1.11 which is standards and 11.1.13 which is scored	17%	
11.2	TRACK TO TRAIN DATA COMMUNICATIONS.	Scored	83%	
12	**MAINTENANCE AND OPERATIONS.**			**0%**
12.1	UNIT MAINTENANCE.	Part of maintenance regime	0%	
12.2	UNIT REPAIRS.	Part of maintenance regime	0%	
12.3	DOCUMENTATION	Part of maintenance regime	0%	
12.4	TRAINING	Part of maintenance regime	0%	
13	**MOCK UPS.**			**1%**
13.1	GENERAL	Scored	30%	
13.2	CAB MOCK UP.	Scored	30%	
13.3	SALOON MOCK UP.	Scored	30%	
13.4	FRONT END SCALE MODEL	Score	10%	
				100%

Table K4 TIIS scoring matrix

Clause	Description	Comments	Percentage of section attributed to scored aspects	Section Totals
1	INTRODUCTION	N/A	0%	
2	INFRASTRUCTURE TRAIN INTERFACES	N/A	0%	
2.1	GAUGE	Scored except TIIS_42 which is standards and TIIS_1584 which is Stage 1	50%	**15%**
2.1.1	SWEPT ENVELOPE	Assessed in Stage 1 as part of 2.1 except 1591and 1597 which are scored	50%	
2.1.2	PLATFORMS	N/A	0%	
2.1.2.1	PLATFORM STEPPING DISTANCES	Standards	0%	
2.1.2.2	PLATFORM LENGTH	Stage 1	0%	
2.2	WHEEL-RAIL INTERFACE	N/A	0%	**15%**
2.2.1	CONTACT PATCH ENERGY	Stage 1 except 1759 which is	25%	

		scored		
2.2.2	TRACK GEOMETRY	Scored	75%	
2.3	STRUCTURES	Stage 1	0%	**0%**
2.4	ENERGY	Scored except 234 which is Stage 1 and 237 which is standards	5%	**20%**
2.4.1	25kV AC	N/A	0%	
2.4.1.1	MAX & MIN SYSTEM VOLTAGES (AC)	Standards	0%	
2.4.1.2	LINE CURRENT LIMITS (AC)	Scored	10%	
2.4.1.3	FAULT LEVEL	Scored	5%	
2.4.1.4	OLE/PANTOGRAPH	Scored 1561, 1562, 244, 247, 1862, 1863, 1864, 1097, 1754, 1793, 253, 260, 268, 1569 Stage 1 1785, 1841, 1751, 1765, Standards 1098, 1560, 1096, 1558	5%	
2.4.1.5	AUTOMATIC POWER CONTROL	Scored 1570 Standard 1213	5%	
2.4.1.6	REGENERATIVE BRAKING (AC)	Scored 1571, 1572, 1573, 1940 Standards 1719	5%	
2.4.2	750V DC	N/A	0%	
2.4.2.1	MAX & MIN SYSTEM VOLTAGES (DC)	Standards 1106	0%	
2.4.2.2	LINE CURRENT LIMITS (DC)	Scored 1574, 1575, 1576, 1110, 1116	30%	
2.4.2.3	REGENERATIVE BRAKING (DC)	Scored except 1118 which is standards	10%	
2.4.2.4	CURRENT COLLECTOR PERFORMANCE	Scored except Stage 1 1766 Standards 1718	5%	
2.4.3	AC/DC CHANGEOVER	N/A	0%	
2.4.3.1	PROPOSED ARRANGEMENTS	N/A	0%	
2.4.3.2	CHANGEOVER ON THE MOVE	Scored	5%	
2.4.3.3	AUTOMATIC CHANGEOVER	Scored except 1721 which is Stage 1	10%	
2.4.3.4	CHANGEOVER WHILE STATIONARY	Scored	5%	
2.5	TRAIN CONTROL SYSTEMS	Stage 1	0%	**15%**
2.5.1	SIGNALLING	Stage 1	0%	
2.5.2	DRIVER-SIGNALLER COMMUNICATION	Stage 1 except 1747 which is scored	3%	
2.5.3	SIGNALLING PRINCIPLES	N/A	0%	
2.5.3.1	ACCELERATION	N/A	0%	
2.5.3.2	BRAKING	Stage 1	0%	
2.5.4	TRAIN DETECTION SYSTEMS	N/A	0%	
2.5.4.1	TRACK CIRCUITS	Standard (1640) except 1638 which is scored	3%	
2.5.4.2	TRAIN LOCATION DETERMINED ONBOARD	Scored	6%	
2.5.5	AUTOMATIC WARNING SYSTEM	Stage 1 (326) except 1653 and 1942 which are scored	9%	
2.5.6	TRAIN PROTECTION AND WARNING SYSTEM	Scored	9%	
2.5.7	AUTOMATIC TRAIN OPERATION	Stage1 1194 Scored 1924	6%	

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2.5.7.1	STOPPING ACCURACY	Stage1 1894	0%	
2.5.7.2	EMERGENCY CUT OUT	Stage 1	0%	
2.5.7.3	ENGAGING AND RELEASING ATO	Scored	3%	
2.5.7.4	DATA COMMUNICATION SYSTEMS FOR ATO	Scored	9%	
2.5.7.5	PERFORMANCE AND RESPONSE TIMES	Scored	13%	
2.5.7.6	STATION STOPS	Stage 1	0%	
2.5.7.7	TRAIN CONTROL SYSTEMS SELF-TEST AND UPGRADES	Scored	6%	
2.5.8	EUROPEAN TRAIN CONTROL SYSTEM	Stage 1	0%	
2.5.8.1	STAGED COMMISSIONING	Scored	3%	
2.5.8.2	ADVISORY SPEED	Scored	3%	
2.5.9	EUROPEAN RAIL TRAFFIC MANAGEMENT SYSTEM	N/A	0%	
2.5.9.1	OPERATION WITH DUAL FITTED INFRASTRUCTURE	N/A	0%	
2.5.9.2	ATP ASPECT	Scored	3%	
2.5.9.3	ERTMS SPECIFICATIONS	Standard 343 Scored 1695	9%	
2.5.9.4	TRAIN COMPLETE	Scored	6%	
2.5.10	GSM-R RADIO	Stage 1 1493 1494 for info	0%	
2.5.11	AUTOMATIC SELECTIVE DOOR OPENING	Scored except 358 which is Stage 1	9%	
2.6	INFRASTRUCTURE MONITORING	Scored	44%	**10%**
2.6.1	FORWARD FACING & REARWARD FACING CCTV	Scored	27%	
2.6.2	OFF TRAIN EQUIPMENT	Scored	18%	
2.6.3	AUTOMATIC VEHICLE IDENTIFICATION	Scored	11%	
2.7	ELECTRO MAGNITIC COMPATIBILITY	Standards 554, 555, 556, 561 Scored 553, 559	100%	**5%**
2.7.1	HARMONICS	Standards		
3	OPERATIONAL INTERFACES	N/A	0%	**20%**
3.1	TRAIN DISPATCH	Scored except 1767 which is standards	6%	
3.2	DRIVER MONITORING OF DOORS	Scored	50%	
3.3	CUSTOMER INFORMATION SYSTEMS	Scored	8%	
3.4	PERSONS WITH REDUCED MOBILITY	Scored	8%	
3.5	NOISE	Scored	8%	
3.6	EMERGENCY EGRESS	Scored (1958)	20%	
ANNEX A	SWEPT ENVELOPES	N/A		
ANNEX B	LIST OF ROUTES	N/A		
ANNEX C	BIDDER SUBMISSION REQUIREMENTS	N/A		

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ANNEX D	INFRSTRUCTURE MONITORING EQUIMENT MONITORING PARAMETERS	N/A		
ANNEX E	PLATFORM DATA	N/A		
ANNEX F	ABBREVIATIONS AND DEFINITIONS	N/A		
ANNEX G	REQUIREMENT IDENTIFIER INDEX	N/A		
ANNEX H	Tg CURVE DEFINITION	N/A		
				100%

Freedom of Information Request – Crossrail

The following email was sent as a Freedom of Information request on 22 June 2016 to foi@crossrail.co.uk

> *Dear Crossrail Limited,*
>
> *For my research I would like to see a copy of the Pre-Qualification Questionnaire that was used in the tender process for the procurement of the crossrail rolling stock and associated services.*
>
> *The OJEU that references this PQQ is 2010/S 148-229137*
>
> *This PQQ was the early part of the competitive tender process, which was eventually won by Bombardier.*
>
> *Yours faithfully,*
>
> *Michael King*

The following reply was received via email on 23 June 2016 and is copied below.

> *Dear Mr King,*
>
> *Thank you for your request for a copy of the Pre-qualification questionnaire for the Crossrail rolling stock and depot procurement process. I am taking action now to address your request. However the team responsible for the rolling stock procurement was dissolved following the award of the contract so it may take some _me to locate this document. In the meantime you may be interested in the documents already in the public domain – the invitation to tender and the draft Rolling Stock and Depot Provision Agreement. The relevant links to the House of Commons Library are as follows:*
>
> *http://data.parliament.uk/DepositedPapers/Files/DEP2013-0765/Ashurst_Rolling_Stock_and_Depot_Service_Provision_Agreement_Part 1.pdf*

http://data.parliament.uk/DepositedPapers/Files/DEP2013-0765/Ashurst_Rolling_Stock_and_Depot_Service_Provision_Agreement_Part2.pdf

http://data.parliament.uk/DepositedPapers/Files/DEP2013-0765/Ashurst_Rolling_Stock_and_Depot_Service_Provision_Agreement_Part3.pdf

http://data.parliament.uk/DepositedPapers/Files/DEP2013-0765/Crossrail_Rolling_Stock__Depot_Services_Instructions_for_Tenderers.pdf

In accordance with the requirement of the Freedom of Information Act I will respond to you further within 20 working days.

Yours sincerely

Patrick Griffin | Freedom of Information

A further response to my request was sent 18 July 2016 and is copied below.

Dear Mr King,

In your message of 22 June 2016 you requested information in accordance with the Freedom of Information Act in respect of the Crossrail rolling stock procurement process.. You made the following request:

For my research I would like to see a copy of the Pre-Qualification Questionnaire that was used in the tender process for the procurement of the Crossrail rolling stock and associated services.

The OJEU that references this PQQ is 2010/S 148-229137.

This PQQ was the early part of the competitive tender process, which was eventually won by Bombardier.

I can confirm that Crossrail Ltd (CRL) does hold the information you have requested.

Further to my earlier response I now enclose a copy of Part D of the Pre-qualification pack for the Rolling Stock and Depot Services Contract, the Pre-qualification Questionnaire..

Please see the information below for details of your right to appeal if you are dissatisfied with this response or the way that your request has been handled.

Yours sincerely

Patrick Griffin | Freedom of Information Officer

Crossrail rolling stock OJEU Notice (Official Journal of the European Union)

This notice in TED website: http://ted.europa.eu/udl?uri=TED:NOTICE:356965-2010:TEXT:EN:HTML

UK-London: rolling stock
2010/S 233-356965

CONTRACT NOTICE - UTILITIES

Services

SECTION I: CONTRACTING ENTITY

I.1) **NAME, ADDRESSES AND CONTACT POINT(S)**
Transport for London
c/o Crossrail Ltd, CS28/G4/14, 25 Canada Square, Canary Wharf
Attn: Mr Roger Davies
E14 5LQ London
UNITED KINGDOM
Tel. +44 2032299978
E-mail: RSD@crossrail.co.uk
Internet address(es)
General address of the contracting entity www.tfl.gov.uk
Address of the buyer profile https://crossrail.bravosolution.co.uk
Further information can be obtained at: As in above-mentioned contact point(s)
Specifications and additional documents (including documents for a dynamic purchasing system) can be obtained at: As in above-mentioned contact point(s)
Tenders or requests to participate must be sent to: As in above-mentioned contact point(s)

I.2) **MAIN ACTIVITY OR ACTIVITIES OF THE CONTRACTING ENTITY**
Railway services

SECTION II: OBJECT OF THE CONTRACT

II.1) **DESCRIPTION**

II.1.1) **Title attributed to the contract by the contracting entity**
Crossrail rolling stock and depot services.

II.1.2) **Type of contract and location of works, place of delivery or of performance**
Services
Service category: No 27
Main place of performance London, South East and East of England.
NUTS code UK

II.1.3) **The notice involves**
A public contract

II.1.4) **Information on framework agreement**

II.1.5) **Short description of the contract or purchase(s)**
Crossrail will connect the City, Canary Wharf, the West End and Heathrow Airport to commuter areas east and west of London. This contract covers the design, manufacture, testing, commissioning and introduction of a fleet of new main line electric commuter passenger trains, design and construction of a new maintenance depot and associated equipment together with the maintenance of these and all ancillary requirements necessary

to provide a specified level of services over a long-term service period together with all associated private finance.

II.1.6) **Common procurement vocabulary (CPV)**
34620000, 34600000, 45234112, 50222000, 66100000

II.1.7) **Contract covered by the Government Procurement Agreement (GPA)**
Yes

II.1.8) **Division into lots**
No

II.1.9) **Variants will be accepted**
Yes

II.2) **QUANTITY OR SCOPE OF THE CONTRACT**

II.2.1) **Total quantity or scope**
The scope is expected to include:
(a) Design, manufacture, testing, commissioning and delivery of adequate numbers of trains to meet specified service levels throughout each day up to and including approximately 57 diagrams (subject to finalisation of operational requirements). The trains are to be of 200m nominal length (during early stages of the service, a limited number of diagrams will require use of 160m nominal length trains). The trains must have a design life of 35 years and be capable of achieving high levels of reliability and performance (including passage of at least 24 trains per hour in the central tunnel section of the route). The scope also includes spares, special tools, cab simulators and other ancillary items;
(b) Integration and installation of on-board signalling equipment to work with the train systems. This will include Train Protection and Warning System (TPWS), Automatic Warning System (AWS), European Train Control System (ETCS) and, for the central tunnel section, Automatic Train Operation (ATO). The central tunnel section will either be Communication Based Train Control (CBTC) (incorporating ATO) with an upgrade path to ETCS with ATO or ETCS with ATO from the outset. Further details of the arrangements for supply of on-board signalling systems will be provided in the invitation to negotiate and economic operators should note that the contracting entity reserves the right either to nominate a supplier or to free issue some or all of the on-board equipment. Lineside signalling systems are not included in this procurement;
(c) Design and construction of a maintenance and operations depot and associated facilities on a site to be provided by the contracting entity at Old Oak Common;
(d) Provision of maintenance services as necessary to meet specified availability and reliability levels over the duration of the contract (anticipated to be up to 35 years from the handover of the last train) provided that the contract may contain the ability to change the scope of the maintenance services during the contract term and/ or require certain maintenance services to continue to be provided notwithstanding termination of other parts of the services;
(e) Arranging finance as required to fund (a) to (d). Further information will be provided in the invitation to negotiate. The contracting entity reserves the right to: (a) run a separate funding competition and / or (b) directly finance any part of the required funding or services and/or (c) procure the finance or services on a batched basis.
The scope excludes the operation of the rolling stock. It is envisaged that the contracting entity will introduce a Crossrail Train Operating Company (CTOC) to do this.
In relation to the scope of this contract, see further section II.2.2 below on options. Further information will be provided in the invitation to negotiate.
estimated cost excluding VAT

Rangebetween 1 000 000 000 and 1 900 000 000 GBP

II.2.2) **Options**

Yes

description of these options: Options will include:

(a) provision of additional trains, depot facilities and associated services to provide up to 15 additional diagrams;

(b) upgrade of on-board signalling equipment to ETCS with ATO (unless fitted at the outset);

(c) additional power supply equipment and associated work to allow operation on 3rd rail fitted routes.

All of the above options will be further explained in the pre-qualification pack and in the invitation to negotiate.

II.3) **DURATION OF THE CONTRACT OR TIME LIMIT FOR COMPLETION**

Duration in months: 480 (from the award of the contract)

SECTION III: LEGAL, ECONOMIC, FINANCIAL AND TECHNICAL INFORMATION

III.1) **CONDITIONS RELATING TO THE CONTRACT**

III.1.1) **Deposits and guarantees required**

Requirements will be set out in the invitation to negotiate.

III.1.2) **Main financing conditions and payment arrangements and/or reference to the relevant provisions regulating them**

Tenderers will be required to arrange finance as required to fund the scope described in II.2.1 above. Further information will be provided in the invitation to negotiate. The contracting entity reserves the right to:

(a) run a separate funding competition and / or

(b) directly finance any part of the required funding or services and/or

(c) procure the finance or services on a batched basis.

III.1.3) **Legal form to be taken by the grouping of economic operators to whom the contract is to be awarded**

Upon Contract Award the contracting entity will enter into a contract with a single legal entity. Therefore, economic operators may form partnerships, limited companies (or equivalent), joint ventures or similar.

III.1.4) **Other particular conditions to which the performance of the contract is subject**

Yes

Requirements will be set out in the invitation to negotiate.

III.2) **CONDITIONS FOR PARTICIPATION**

III.2.1) **Personal situation of economic operators, including requirements relating to enrolment on professional or trade registers**

Information and formalities necessary for evaluating if requirements are met: Interested parties must register for pre-qualification for the Rolling Stock and Depot procurement via the buyer profile site https://crossrail.bravosolution.co.uk. Following registration parties will be able to download a Pre-qualification Pack which will include a questionnaire and guidance notes.

III.2.2) **Economic and financial capacity**

See Pre-qualification Pack.

III.2.3) **Technical capacity**

Information and formalities necessary for evaluating if requirements are met See Pre-qualification Pack.

III.2.4) **Reserved contracts**

No

III.3) **CONDITIONS SPECIFIC TO SERVICES CONTRACTS**

III.3.1) **Execution of the service is reservedto a particular profession**

III.3.2) **Legal persons should indicate the names and professional qualifications of the staff responsible for the execution of the service**
No

SECTION IV: PROCEDURE

IV.1) **TYPE OF PROCEDURE**

IV.1.1) **Type of procedure**
Negotiated
Candidates have already been selected No

IV.2) **AWARD CRITERIA**

IV.2.1) **Award criteria**
The most economically advantageous tender in terms ofthe criteria stated in the specifications or in the invitation to tender or to negotiate

IV.2.2) **An electronic auction will be used**
No

IV.3) **ADMINISTRATIVE INFORMATION**

IV.3.1) **File reference number attributed by the contracting entity**
X2234

IV.3.2) **Previous publication concerning the same contract**
Periodic indicative notice
Notice number in OJ: 2010/S 148-229137 of 30.7.2010

IV.3.3) **Conditions for obtaining specifications and additional documents**

IV.3.4) **Time limit for receipt of tenders or requests to participate**
24.1.2011 - 12:00

IV.3.5) **Language(s) in which tenders or requests to participate may be drawn up**
English.

IV.3.6) **Minimum time frame during which the tenderer must maintain the tender**

IV.3.7) **Conditions for opening tenders**

SECTION VI: COMPLEMENTARY INFORMATION

VI.1) **THIS IS A RECURRENT PROCUREMENT**
No

VI.2) **CONTRACT(S) RELATED TO A PROJECT AND/OR PROGRAMME FINANCED BY COMMUNITY FUNDS**
No

VI.3) **ADDITIONAL INFORMATION**
Economic operators shall note the following:
1. Whilst the contracting entity stated in I.1 is Transport for London (TfL), the contract or contracts (if any) resulting from this call for competition may be awarded by and may be for the benefit of TfL and/or any of its subsidiaries and nominees. TfL is a complex organisation operating both as a functional body of the Greater London Authority under the direction of the Mayor of London and as a provider of transport services. Further information on TfL may be found at www.tfl.gov.uk;
2. The description provided in II.1.5 and the scope described in section II.2.1 represent the current anticipated requirement. The contracting entity reserves the right to amend the description and/or the scope and/or adjust the duration of the contract as a result of emerging operational requirements;

3. References to the minimum requirements to be met by any variant submitted and any specific requirements for the presentation of an offer containing variants will be included in the pre-qualification pack and the invitation to negotiate;
4. The estimated value range stated in section II.2.1 is the estimated capital cost of the rolling stock and depot excluding annual maintenance costs and the successful economic operator's tendering and contract administration costs. The estimates are based on 2010 prices and exclude the future effects of inflation and the cost of providing finance which should be assessed by economic operators based on their circumstances. On the same basis, the contracting entity estimates that average annual maintenance costs will be in the range of £25m p.a. to £50m p.a. These estimates could vary depending on the number of trains which economic operators determine are actually required to meet the specified number of diagrams and the extent and timing of the exercise of any variations, maintenance changes or options pursuant to the contract. TfL may also wish in future to purchase additional trains or component parts for use elsewhere on its rail portfolio;
5. The duration of the contract stated in section II.3 is an estimate based on an initial contract period with possible extensions up to a total of 40 years (480 months) or more. Further information about contract duration and extensions will be included in the pre-qualification pack and the invitation to negotiate;
6. Economic operators must complete the pre-qualification questionnaire which can be accessed through the Crossrail eSourcing Portal after registering. Registering is only required once.
Registering: Economic operators should browse to the eSourcing Portal (www.crossrail.bravosolution.co.uk) and complete the following:
a) Click the "Click here to register" link;
b) Accept the terms and conditions and click "continue";
c) Enter your business and user details;
d) Note the username you use and click "Save" when complete;
e) You will then receive an e-mail with your unique password.
Post registration access to the pre-qualification questionnaire and information pack (PQQ):
a) Login to the Crossrail eSourcing Portal with your unique Username and password;
b) Click on the "PQQs Open to All Suppliers" link;
c) Click on the pre-qualification pack entitled "Rolling Stock & Depot Services";
d) Click the "Express Interest" button (this will make the "PQQ" visible in the economic operator's "My PQQ" box). This is a secure area for projects only;
e) Click on the PQQ code. The economic operator can now access any attachments by clicking the "Buyer Attachments" in the "PQQ details" area;
f) Download the documents relating to the pre-qualification questionnaire. Click on the bold and underlined filename to open the attachments.
Select "Save" and store on your PC.
Responding to the pre-qualification questionnaire:
a) In the "PQQ details" area under "My Response" the economic operator must now choose "Create Response" or "Decline to Respond" (please give a reason if declining to respond);
b) Economic operators can now use the messages functions to communicate with Crossrail and seek clarification;
c) Please note the deadline for completion, this is a precise time and the eSourcing portal will reject the economic operators prequalification questionnaire if it is submitted after this time;
d) Economic operators should click the "Submit Response" button when they wish to submit the final completed pre-qualification questionnaire. Please note that there is detailed online help.

For further assistance contact the BravoSolution helpdesk which is available Monday to Friday (8:00 AM to 6:00 PM) BST on a) email – help@bravosolution.co.uk or
b) telephone – +44 08003684850 / fax +44 02070600480, outside UK +44 2070600490.
7. Economic operators must note that any expression of interest submitted in response to the Periodic Indicative Notice for these services does not apply to this Contract Notice and the above procedure must be followed in order to receive the Pre-qualification Pack. Economic operators must then inform the contracting entity that they are interested in the contract by complying with the requirements of the pre-qualification questionnaire as described above.
A response to this notice does not guarantee that an economic operator will be invited to tender; the process for selection for Bidders to be invited to tender will be set out in the pre-qualification documents. The award process may be terminated or suspended at any time without cost or liability to the contracting entity, TfL or any other party.
TfL does not bind itself to enter into any contract arising out of the procedures envisaged by this notice. No contractual rights express or implied arise out of this notice or the procedures envisaged by it. Any contract let by TfL may contain provision that the contract may be extended at TfL's discretion. TfL reserves the right to vary its requirements and the procedure relating to the conduct of the award process.
8. TfL embraces diversity and welcomes applications from all suitably skilled suppliers of all sizes who can meet the requirements, regardless of gender, ethnicity, sexual orientation, faith, disability or age of supplier workforce and/or ownership. TfL will actively promote green procurement throughout its supply chain and welcome applications from suppliers committed to the principles of reducing, reusing and recycling resources and to the practices of buying recycled. TfL strongly supports and implements the Greater London Authority Group Responsible Procurement Policy, details of which may be found at: http://www.london.gov.uk/rp/policy/. Further details as to the application of Responsible Procurement to this procurement may be set out in the pre-qualification and tender documents.
Note: References to "TfL" includes its subsidiaries and nominees.

VI.4) **PROCEDURES FOR APPEAL**

VI.4.1) **Body responsible for appeal procedures**

VI.4.2) **Lodging of appeals**

Precise information on deadline(s) for lodging appeals: The contracting entity will incorporate a standstill period at the point information on the award of the contract is communicated to tenderers. That notification will provide full information on the award decision. The standstill period, which will be for a minimum of 10 calendar days, provides time for unsuccessful tenderers to challenge the award decision before the contract is entered into. The Utilities Contracts Regulations (SI 2005 No 6) provide for aggrieved parties who have been harmed or are at risk of harm by a breach of the rules to take action in the High Court (England, Wales and Northern Ireland).

VI.4.3) **Service from which information about the lodging of appeals may be obtained**

VI.5) **DATE OF DISPATCH OF THIS NOTICE:**

26.11.2010

Crossrail key technical aspects of the train (released in the ITN stage)

Crossrail Rolling Stock

Crossrail

Crossrail will operate with 57 purpose-built electric trains in service each day, covering the network from Heathrow and Maidenhead in the west, to Abbey Wood and Shenfield in the east.

Each train will have around 450 seats and a capacity for 1,500 passengers overall. Wide through-gangways between carriages, and ample space in the passenger saloons, and around the doors, will reduce passenger congestion while allowing room for those with heavy luggage or pushchairs. Four designated wheelchair spaces will be provided on each train.

Key technical aspects of the trains :

- Maximum Length – 205 metres
- Top Speed – 145 kph (90mph)
- Acceleration – up to 1 m/s^2 (comparable to metro trains)
- Power Supply – 25 KV AC from the overhead line, with potential to convert to 3rd rail capability
- Signalling Systems:
    - Automatic Train Operation in the central tunnel section
    - ETCS signal protection provision for surface running
    - Compatibility with ‘legacy’ train-protection systems until ETCS is fully installed on the national network
- Full Air Conditioning for passengers and drivers
- Evolutionary, not revolutionary technology for utmost reliability from day one
- Strict requirements for weight and suspension design to minimise wear-and-tear on the track
- Each train will have a 350 tonne upper weight limit (unladen)
- Energy-saving features including regenerative braking, real-time on-board energy metering and ‘intelligent control’ of heating and cooling systems
- Energy efficiency of 24 KWh per train kilometre (equivalent of 55g CO_2 per passenger kilometre)
- Compliance with the latest international safety standards for trains running in tunnels
- Continuous updating of passenger journey information
- Integration with Platform Screen Doors at the central section stations

Crossrail rolling stock general requirements in the ITN of April 2013

X2234 IFT Part D

Part D Technical Scope

1. Rolling stock

1.1 General requirements

The Project requires provision of a fleet of new electric multiple units of sufficient size to sustain the provision of 55 Diagrams. The minimum fleet size required by RfL is 60 FLUs.

a) The key features required of the Units can be summarised as:

i) design and construction to meet European Union standards for interoperable main line rolling stock;

ii) a design concept that can accommodate large numbers of passengers for metro style operations in the Central Section but which also provides a comfortable environment for longer journeys to and from the outer suburban areas. Further information is provided in Part D1.2;

iii) a superior on-board experience for passengers through features such as improved whole journey passenger information, air conditioning and a modern and stylish visual appearance;

iv) a vehicle body configuration and an interior layout that allows the rapid movement of passengers on and off the Unit and to support the short dwell times which are key to train service performance through the Central Section;

v) open, wide gangways between individual Vehicles to encourage passenger circulation within the Unit to ease congestion;

vi) a single unit fixed formation trainset concept which uses best practice in sub-system design, component specification, system architecture and recovery capability to deliver "best in class" levels of reliability and service performance including extremely low levels of service affecting failure;

vii) an ergonomically optimised driving cab that permits both manual driving under a range of train protection systems and ATO;

viii) traction and braking performance to support at least 24 trains per hour in the Central Section, provide enhanced operational flexibility in the outer areas and allow ATO to be fully exploited; and

ix) a weight-efficient design that seeks to minimise the whole life cost to the railway system through optimised train/track interaction and reduced energy demand.

b) In particular the Units shall:

i) operate on a 25kV AC overhead electrified system, with capability to retrofit 750V DC 3rd Rail equipment if desired in the future;

ii) have capability for regenerative electrical braking, to assist energy efficiency – the 25kV overhead line infrastructure for the Crossrail route is being specified to sustain maximum receptivity for regenerated current;

iii) be of 205 metres maximum length, but with the capability to configure as a 163 metre maximum length Unit; for initial operation on the surface network, prior to full opening of the Crossrail route;

iv) have a highly efficient and reliable door system that works with platform edge doors at stations in the Central Section, and also has capability for selective door operation at stations with short platforms at the outer ends of the network;

v) have at least 450 seats and accommodate at least 1,500 passengers in total, with the standing passengers at a density of no more than four persons per square metre;

vi) operate and transition between cab signalling systems with an ATO overlay in the Central Section, legacy United Kingdom train protection systems (AWS and TPWS) and ETCS where fitted on surface sections (see Part F2);

vii) be constructed to stringent fire worthiness standards appropriate to the extensive operation in deep tunnel; and

viii) achieve a top speed in the open of 145 kilometres per hour and 100 kilometres per hour in the Central Section.

ix) achieve a reliability target of no less than 45,000 miles MDBSAF. Bidders are free to propose reliability of more than 45,000 miles MDBSAF but if this is in excess of 60,000 miles MDBSAF, Bidders shall follow the Variant Proposal process as described in Appendix B to the IFT.

It is important that the Units are designed taking full account of the passenger, operational and technical environment within which they will work. Background information about these matters can be found in the document CRL1-XRL-R1-GUI-CR001-50002 provided in the Data Room. The SP will be required to cooperate closely with CRL, TfL and Network Rail to deliver an integrated transport system.

The Units will reflect current developments in the rolling stock market and are expected to maximise energy efficiency, increase network capacity and introduce improvements in reliability and general passenger experience.

The successful Bidder will be required to provide a stock of spare parts, any special maintenance tools, driver training Simulator and other operating staff training courses and material.

1.2 Interior and exterior industrial designs

The Train Technical Specification includes Appendix P, comprising interior and exterior industrial design requirements and accompanying visualisations. These are intended to show how the requirements for the Units as set out in the Train Technical Specification

Crossrail ITN technical and deliverability criteria scoring guidelines for train works

Appendix C Technical and deliverability criteria scoring guidelines

Part 1 – Technical Works criteria

1. Train Works

Further to Part C2.2.1, scoring for the technical evaluation of Bidders' proposals for Train Works will be based on the following principles:

Sub-criteria	Relevant requirements, components and weightings (Clause references relate to the Train Technical Specification and are deemed to include other requirements cross referenced in the relevant clauses)		
Physical Construction (5%)	Clause	Component	% of score
	3.1	Unit Lengths & Formations	20%
	3.12	Aerodynamics	10%
	3.18	Unit Construction	50%
	3.28	External Features	4%
	3.24	Couplers, Inter-Vehicle Gangways and Gangway Doors	6%
	3.47	Design Life	10%
Performance (10%)	Clause	Component	% of score
	3.2	Performance/Journey Times	60%
	3.3	Configuration Times	20%
	3.6	Env. Operating Conditions	20%
Energy and Weight (8%)	Clause	Component	% of score
	3.4	Energy Consumption	60%
	3.5	Unit weight targets	40%
Physical Behaviour (10%)	Clause	Component	% of score
	3.7	Gauging, Routes and Stepping Distance	25%
	3.8	Track Wear and T-Gamma	35%
	3.9	Ride & Stability	10%
	3.10	Noise and Vibration	20%
	3.23	Lubrication	10%
Fire (5%)	Clause	Component	% of score

Sub-criteria	Relevant requirements, components and weightings (Clause references relate to the Train Technical Specification and are deemed to include other requirements cross referenced in the relevant clauses)		
	3.11	Fire Performance	100%
Power Systems (7%)	Clause	Component	% of score
	3.13	Traction Supply	20%
	3.14	Traction System	40%
	3.15	Pantographs	10%
	3.16	DC Operation	10%
	3.17	Auxiliary Systems	20%
Brakes (7%)	Clause	Component	% of score
	3.20	Braking System	60%
	3.21	WSP	25%
	3.22	Sanding	15%
Door Systems (10%)	Clause	Component	% of score
	3.29.1	Passenger Door Systems General Requirements	50%
	3.29.2 to 3.29.10 inclusive	Passenger Door Control	50%
Signalling, Control & Cab (12%)	Clause	Component	% of score
	3.30	Train Control and Protection (including signalling & control system interface requirements)	40%
	3.31	Radio Systems	8%
	3.32	OTMR	3%
	3.39	DOO	3%
	3.40	Driving Cab	8%
	3.41	TMS	15%
	3.42	Data Communications	8%
	3.45	EMC	15%
Passenger Environment (6%)	Clause	Component	% of score
	3.33	CCTV	15%

Sub-criteria	Relevant requirements, components and weightings (Clause references relate to the Train Technical Specification and are deemed to include other requirements cross referenced in the relevant clauses)		
	3.35	Passenger Demand Monitoring	10%
	3.36	Lighting	15%
	3.37	HVAC	30%
	3.38	Passenger Information	30%
Reliability (12%)	Clause	Component	% of score
	3.25	Rescue Functionality	10%
	3.43	Reliability and Resilience (including relevant data from other sections)	90%
Industrial Design (6%)	Clause	Component	% of score
	3.19	Exterior Appearance and Livery	40%
	3.34	Passenger Environment	60%
Other Requirements (2%)	Clause	Component	% of score
	3.44	Human Factors	30%
	3.46	Standards	30%
	3.48	Infrastructure Monitoring etc.	20%
	4.5	Mock-ups	20%

Subject to any Qualifications or clarifications provided by Bidders, scoring of the Train Works Technical Criterion will be carried out by reference to Part B of the Bidder's Proposal. The Proposal Template requires this to be structured so that the Train Technical Specification clause references in the above table correspond with the structure of Parts B1.1 and B2.1 of the Proposal. For example:

- the Unit Lengths & Formations component of the Physical Construction sub-criterion is based on Clause 3.1 of the Train Technical Specification and information related to this requirement is expected to be provided by Bidders in Part B1.1 (1) and Part B 2.1 (1) of the Proposal; and
- the Braking System component of the Brakes sub-criterion is based on Clause 3.20 of the Train Technical Specification and information related to this requirement is expected to be provided by Bidders in Part B1.1 (20) and Part B 2.1 (20) of the Proposal.

The two variations to this principle are:

- the Train Control and Protection component of the Signalling, Control & Cab sub-criterion which will additionally take account of the technical elements of Part B3 of the Proposal; and
- the Reliability component which will additionally take account of reliability-related information supplied against individual technical elements (e.g. Item 29 Passenger Bodyside Door Systems).

Scoring of components

CRL will base its score for each of the components listed above on Bidders' compliance with the relevant requirements using the following guidelines:

Score	Characteristics
0%	Proposal and supporting information does not demonstrate that the required functionality will be provided
35%	SP Train Proposal and supporting information do not demonstrate that the required functionality will be provided however, Bidder has provided assurances that the specified functionality will be delivered at the Bidder's risk
55%	Specified functionality is provided by the SP Train Proposal but either: (a) with non-compliances with the Train Technical Specification; and / or (b) a need for derogations from relevant Standards (at the Bidder's risk); and / or (c) supporting information does not fully demonstrate how compliance will be achieved.
75%	Specified functionality is provided. Full compliance with relevant Standards but some non-compliances with the Train Technical Specification and/or minor omissions from the supporting demonstration of compliance
100%	Fully compliant

Glossary

AC	Alternating Current
ANT	Actor-Network Theory
ATOC	Association of Train Operating Companies
BR	British Rail
BRB	British Railways Board
BREL	British Rail Engineering Limited
BRIL	British Rail Investments Limited
BTC	British Transport Commission
CBA	Cost-Benefit Analysis
CME	Chief Mechanical Engineer
CSR	Corporate Social Responsibility Looks at the role of corporations in addressing social and environmental issues. More information at Wikipedia here: https://en.wikipedia.org/wiki/Corporate_social_responsibility
DC	Direct Current
Decision-laboratory	A metaphor used in this research to describe the action taking place to develop articulate propositions. For strategic decisions to produce new trains this decision-laboratory includes the procurement process and more.
DJSI	Dow Jones Sustainability Indices
DMU	Diesel Multiple Unit
EMU	Electric Multiple Unit

EU	European Union
FOI	Freedom of Information
GB	Great Britain
GNER	Great North Eastern Railway
HLOS	High Level Output Specification
HST	High Speed Train
ITT	Invitation To Tender. A typical stage in the procurement process for large bids.
ITN	Invitation To Negotiate. An alternative to ITT (see above) that is used in the Crossrail procurement.
MCA	Multi-Criteria Analysis
MEAT	Most Economically Advantageous Tender. An acronym used for some procurements to summarise the criteria for the winning bid
NGO	Non-Governmental Organisation.
NR	Network Rail
OJEU	Official Journal of the European Union. A set of directives to guide tendering processes across the EU
OPRAF	Office of Passenger Rail Franchising
ORR	Office of the Rail Regulator
PQQ	Pre-Qualification Questionnaire. Typically an early stage in the tender process for large bids
PSO	Public Service Obligation.

PTE	Passenger Transport Executive. A local government body responsible for public transport within large urban areas.
REC	Railway Executive Committee, a government body that operated during World War One and Two to coordinate railways in support of the war effort.
ROSCO	Rolling Stock Operating Companies. Organisations that own and maintain railway engines and carriages which are leased to train operating companies (TOCs).
RSSB	Rail Safety and Standards Board
SIM	Social Issues in Management "…studies the social issues, institutions, interactions, and impacts of management." Source: Academy of Management http://aom.org/Divisions-and-Interest-Groups/Social-Issues-in-Management/Social-Issues-in-Management.aspx
SoFA	Statement of Funds Available
SRA	Strategic Rail Authority
STS	Science and Technology Studies. "…the study of how social, political, and cultural values affect scientific research and technological innovation, and how these, in turn, affect society, politics and culture." Source: Wikipedia (https://en.wikipedia.org/wiki/Science,_technology_and_society)
TOC	Train Operating Company. An organisation running the operational passenger rail service within Great Britain
UIC	The International Union of Railways (Union Internationale des Chemins de fer)